Technical Report 2000-5

IDAHO COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT

MIGRATION OF ADULT SPRING AND SUMMER CHINOOK SALMON PAST COLUMBIA AND SNAKE RIVER DAMS, THROUGH RESERVOIRS AND DISTRIBUTION INTO TRIBUTARIES, 1996

A report for Project MPE-P-95-1

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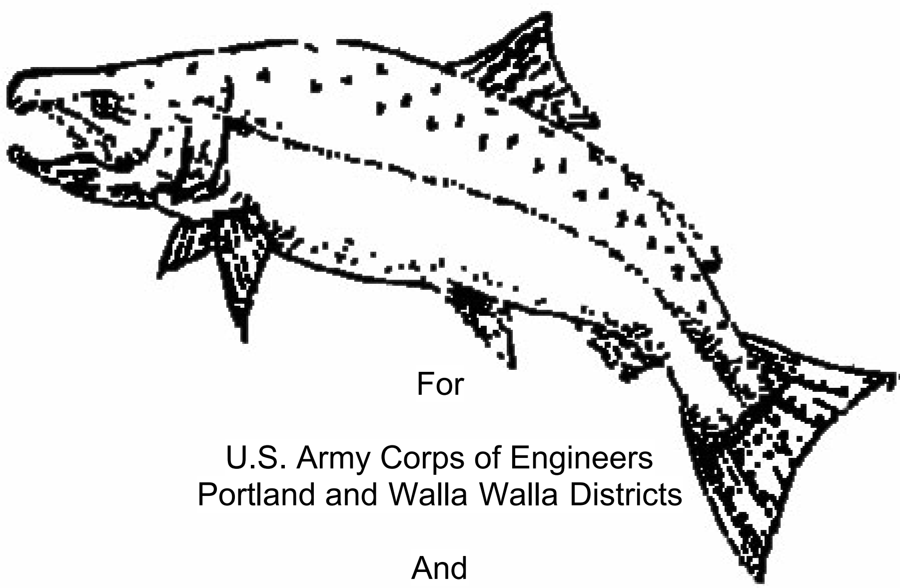

For

U.S. Army Corps of Engineers
Portland and Walla Walla Districts

And

Bonneville Power Administration
Portland, Oregon

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Preface

Recent studies of adult salmon and steelhead migrations past dams, through reservoirs, and into tributaries with radio telemetry began in 1990 with planning, purchase and installation of equipment for studies at the Snake River dams. Adult spring and summer chinook salmon were outfitted with transmitters at Ice Harbor Dam in 1991 and 1992, at John Day Dam in 1993 and reports of those studies are available (Bjornn et al. 1992; 1994; 1995; 1998). The focus of adult salmon passage studies was shifted to the lower Columbia River dams in 1995 when telemetry equipment was set up at the dams and in tributaries, and spring/summer chinook salmon were outfitted with transmitters at Bonneville Dam in 1996. In this report we present information on the overall migration of chinook salmon from release, past each of the dams in the Columbia and Snake Rivers and into tributaries in 1996. Additional reports will be issued on detailed analysis of passage at dams that had a full complement of receivers and antennas to monitor use of fishway entrances and passage through transition pools. Reports will also be produced that cover studies of passage of steelhead.

Acknowledgments

Many people assisted in the field work and data compilation for this project and the successful completion was made possible by Bob Dach and Teri Barila, the Corps of Engineers project officers at the time. Michelle Feeley, Brian Hastings, Michael Jepson, and Jay Nance assisted in project operations and data processing and analysis.

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Abstract

We captured 853 spring and summer chinook salmon *Oncorhynchus tshawytscha* in the adult trapping facility at Bonneville Dam in 1996, released them with radio transmitters, and studied their passage past dams, through reservoirs and into tributaries. Radio receivers were set up at Columbia and Snake river dams and at the mouths of major tributaries to monitor movements of salmon. Recaptures of salmon at hatcheries, weirs and traps, and data from mobile tracking were used to complete the migration history.

Of 853 salmon released downstream with transmitters, 703 were classified as spring chinook salmon and 150 as summer chinook salmon. At the release site, 15 chinook salmon regurgitated transmitters and 838 retained transmitters. Of the 838 fish, 99% were recorded back at the Bonneville Dam tailrace and 96.5% were known to have passed the dam. Fifty-nine percent of the 838 fish passed The Dalles Dam, 45% passed John Day Dam, 36% passed McNary Dam, 14% passed Ice Harbor Dam, 14% passed Lower Granite Dam and 14% passed Priest Rapids Dam.

Median times for chinook salmon to pass individual Columbia River dams ranged from 0.93 d at The Dalles Dam to 1.51 d at Priest Rapids Dam. Median passage times at the monitored Snake River dams were 0.75 d at Ice Harbor Dam and 1.59 d at Lower Granite Dam, where operation of the adult trap extended passage times for fish diverted into the trap. From release downstream from Bonneville Dam, median passage times past multiple dams were 11.9 d to the top of McNary Dam, 16.8 d to the top of Ice Harbor Dam, 27.2 d to the top of Lower Granite Dam and 16.7 d to the top of Priest Rapids Dam.

Adult chinook salmon passed most tailrace receiver sites throughout the day and night, but typically moved through fishways and past top-of-ladder receivers during daylight hours. Most chinook salmon that were in fishways at nightfall did not pass the dam until the next day.

Summer chinook salmon migrated more rapidly than spring chinook salmon, with median passage times about 66% of those of spring chinook salmon. Median passage rates for spring and summer chinook salmon through lower Columbia River reservoirs were 43 km/d through the Bonneville pool, 45 km/d through The Dalles pool, 62 km/d through the John Day pool and 56 km/d through the McNary pool. Median passage times through the Bonneville and The Dalles reservoirs were significantly ($P < 0.005$) shorter for summer chinook salmon than for spring chinook salmon.

Periods of relatively high flow and spill in 1996, and a block of turbid water in late April/early May appeared to delay passage of salmon with and without transmitters. Nadirs in chinook salmon counts at dams and in passage of chinook salmon with transmitters coincided with high flow and spill in late May and into June, particularly at Lower Granite and Ice Harbor dams. Sharp drops in chinook salmon counts also occurred during periods of high turbidity; the largest declines were during early-May at

Bonneville Dam and during mid-May at Ice Harbor and Lower Granite dams. Passage times at individual dams, however, were not strongly correlated with flow, spill, or turbidity.

Cumulative passage times were best predicted by the date that fish first passed into the Bonneville Dam tailrace, with summer chinook salmon migrating at faster rates than spring chinook salmon. The number of times salmon fell back over dams was also a good predictor of passage times, because fish with one or more fallbacks during their migration had significantly lower migration rates. Movement back out into the tailrace from the fishways also contributed to significantly longer times to pass upriver sites for some sites. Secchi disk depths, spill, and flow at lower Columbia River dams explained relatively low proportions of the variability in passage times past multiple dams. High spill was correlated with higher fallback rates at Bonneville, The Dalles, and John Day dams and thus had some indirect effect on passage times. Environmental conditions at Lower Granite Dam accounted for more than 35% of the variability in passage times from the Ice Harbor tailrace to the top of Lower Granite Dam.

A total of 185 chinook salmon, 23% of the fish with transmitters that passed Bonneville Dam, fell back over or through Bonneville or other dams 326 times in 1996. Forty-one percent of all fallback events occurred at Bonneville Dam and 12 to 15% of the fish that passed Bonneville, The Dalles and John Day dams fell back. About 9% of the fish that passed McNary and Ice Harbor dams fell back, 5% fell back after passing Priest Rapids and 1% fell back after passing Lower Granite Dam. Fallback rates increased with high flow and spill, but correlations were not strong.

Fallbacks at any dam added significantly to overall passage time past multiple dams. Using median passage times, one or more fallbacks at any dam added approximately five days to overall passage time when compared to chinook salmon that did not fall back. Differences in median passage times between fish that did and did not fall back were greater for spring chinook salmon than for summer chinook salmon. For all chinook salmon, the number of cumulative fallback events by individual fish was correlated with longer passage times. One or more fallback events at any location added from 4.1 to 6.7 d to median times from release to passage at upriver dams , differences that were significantly ($P < 0.05$) longer than for fish that did not fall back.

About 66% of chinook salmon that fell back subsequently reascended all dams at which they fell back. Of the remaining 34%, about half were recorded in tributaries downstream from the location of the fallback event and half were not accounted for in tributaries or fisheries. From 66 to 74% of chinook salmon that fell back at lower Columbia River dams eventually returned to tributary sites up- or downstream from the dam where they fell back. By comparison, the fish that fell back at Lower Granite Dam was subsequently recorded in an upriver tributary, 100% of those that fell back at Ice Harbor Dam entered tributaries (78% upriver and 22% in the Umatilla River), and all fish that fell back at Priest Rapids Dam reascended.

Fish that fell back over dams and then reascended ladders added positive biases to fish counted at the dams. Spring and summer chinook salmon counts reported in the 1996 USACE annual fish passage report were inflated by an estimated 2,600 to 9,250 fish at lower Columbia River dams and from about 75 to 700 fish at Ice Harbor, Lower Granite, and Priest Rapids dams. Adjustment factors for that fell b ack and reascended ranged from 0.86 at Bonneville Dam and 0.85 at The Dalles Dam to 0.99 at Lower Granite Dam.

About 71.4% of the chinook salmon that fell back at Bonneville Dam survived to enter major tributaries or pass over the top of Priest Rapids Dam, while the survival rate for fish that did not fall back was 77.7%, a difference of about 6%. When we included fish that returned to Lower Granite trap without transmitters as survived, salmon that did not fall back at Bonneville Dam survived at significantly ($P < 0.10$) higher rates than fish that did fall back at Bonneville Dam (79.3% versus 72.3%). Survival to tributaries for chinook salmon that fell back at any dam was 74.1%, compared to 77.7% for fish that did not fall back at any location, a difference that was not significant ($P > 0.10$).

Chinook salmon arrived at tributaries in a predictable progression from lower Columbia River to upriver locations. Migrations into individual tributaries were typically spread over 6 to 8 weeks, with fish recorded at tributary mouths throughout the day and night.

In 1996, about 70% of spring chinook salmon with transmitters were last recorded in the lower Columbia River and its tributaries. The highest number of summer chinook salmon were last recorded at Priest Rapids Dam or in tributaries upriver from the dam. Summer chinook salmon also made up substantial portions of the returns to the Imnaha, Klickitat and Salmon rivers. Overall, final distribution for all chinook salmon outfitted with transmitters appeared to reflect the general distribution of Columbia River spring and summer chinook salmon runs in 1996.

Final distribution records were also linked to dates when specific stocks passed Bonneville Dam. Some, like Snake River and Deschutes River stocks passed Bonneville Dam throughout the migration season, while lower- and mid-Columbia stocks were more clearly associated with spring or summer portions of the 1996 run.

About 20% of the chinook recorded at Ice Harbor Dam and about 5% of the fish that passed Priest Rapids Dam made temporary excursions into lower Columbia River tributaries. Most tributary dip-ins were for less than one day. Stocks that returned to lower- Columbia River tributaries also entered a variety of other tributaries, in some cases at higher rates than upriver stocks.

Although there were limitations in our ability to monitor survival to tributaries, we calculated survival rates of approximately 76% for all chinook salmon that retained transmitters after release. About 90% of summer chinook salmon survived to tributaries or to the top of Priest Rapids Dam (above which telemetry coverage was limited), a rate that was significantly ($P < 0.01$) higher than the 73% survival rate for spring chinook salmon. A significantly ($P < 0.05$) higher percentage (78%) of chinook salmon without fin clips survived to enter tributaries than fish with fin clips (70%). Of about 200 fish (24% of those that retained transmitters after release) that did not survive to enter tributaries, about 20% were recaptured in fisheries and reported to us, and the fate of the remaining 80% was mostly unknown.

Approximately 40% of all chinook salmon outfitted with transmitters in 1996 were recaptured in fisheries, at hatcheries, weirs or traps (not including the Bonneville or Lower Granite traps), at spawning grounds, or their transmitters were found along river corridors. Fifteen percent of reported recaptures were in sport fisheries, 13% in tribal fisheries, 61% at hatcheries, weirs or traps and 11% at spawning grounds or along migration routes. One-third of all recaptures were at hatcheries in the Wind, Little White Salmon and Deschutes rivers and another 13% were in those tributaries at locations other than hatcheries. Twelve percent of all recaptures in 1996 were in the Snake River drainage, 18% were in the mid-Columbia or its tributaries upriver from McNary reservoir, and 13% were in the Columbia River downstream from McNary Dam.

Our best estimate of the final fate for all radio-tagged spring and summer chinook salmon in 1996 was 6.2% downstream from Bonneville Dam, 59.6% between Bonneville and McNary dams, 19.2% in the mid-Columbia upstream from McNary Dam, and 14.7% in the Snake River basin. Returns to the lower Columbia River were mostly spring chinook salmon, while summer chinook salmon returned mostly to the mid-Columbia and Snake rivers. Escapements were 37% to tributaries and 22.6% to hatcheries; when we included fish that passed over Priest Rapids Dam and the Lower Granite trap, total escapement was 68.5%. About 10.6% were recaptured in sport or tribal fisheries, 2.3% of transmitters were found in non-spawning areas, and 18.3% were unaccounted for.

Fish that were unaccounted for may have been harvested but not reported to us, may have regurgitated transmitters that were not recovered or located, may have entered tributaries undetected, may have spawned at main stem locations, or may have died and were not detected as mortalities. More than 95% of the unaccounted for fish with transmitters were last recorded in the hydrosystem downstream from Lower Granite and Priest Rapids dams, and 92% were spring chinook salmon.

Introduction

Studies of the passage of adult chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* at the lower Columbia River dams began in 1995 with the setup of radio telemetry equipment, and fish were outfitted with transmitters in 1996. In this report, we present information on passage of spring and summer chinook salmon at each of the dams, beginning with Bonneville Dam, and their migrations through reservoirs and into tributaries wherever monitored throughout the basin in 1996. Data presented in this report can be compared to migration rates and passage success of adult spring and summer chinook salmon at dams and through reservoirs in the lower Snake River that were assessed in 1991-1993 (Bjornn et al. 1998). As in the Snake River studies, radio telemetry was used to monitor salmon movements at the dams, up the rivers, and into tributaries.

The study described herein was undertaken because of concerns of the Corps of Engineers (Corps), state and federal fish agencies and tribes, those expressed in section 603 of the Northwest Power Planning Council's (NPPC) 1987 Columbia River Basin Fish and Wildlife Program, and later reflected in the Biological Opinion on 1994-1998 operation of the Federal Columbia River Power System, that studies were needed to ensure that passage of adult salmon and steelhead past the dams and through the reservoirs was as efficient as possible.

Study plans were developed in consultation with Corps of Engineers personnel, and with biologists in other federal, state, and tribal fish agencies. Research was conducted by personnel of the Idaho Cooperative Fish and Wildlife Research Unit (ICFWRU) and National Marine Fisheries Service with logistical support, cooperation, and funding from the Corps of Engineers, Bonneville Power Administration and US Geological Survey.

Passage of chinook salmon at dams and through reservoirs in the lower Snake River was studied in 1991-1993 (Bjornn et al. 1992; 1994; 1995; 1998), and the telemetry equipment and procedures developed for those studies were used at the lower Columbia River dams. Because larger numbers of fish were tagged and more receiver sites were used in the 1996 studies, we developed new ways to process the millions of records obtained, and to code the records to identify the migration behavior of the fish to facilitate data analysis.

In 1995, as we started planning for the studies at the lower Columbia River dams, we, and others, were concerned that adult salmon and steelhead taken from the Washington-shore ladder at Bonneville Dam might not be a representative sample of the fish runs that passed the dam. We also wanted to study passage at Bonneville Dam and believed that use of naive fish that had not already passed the dam would be preferred. In the spring of 1995, we attempted to capture adult salmon downstream from Bonneville Dam in trap nets, but with little success. With little hope of capturing adequate numbers of adult salmon downstream from the dam, we decided to use the facilities in the adult fish facility at Bonneville Dam and determine if the fish trapped there were representative of the runs, and if the use of non-naive fish to study passage at Bonneville Dam biased our results in any discernible way. In 1996, we captured salmon in the fish lab, outfitted them with transmitters and transported them to release sites on both sides of the Columbia River about 9.5 km downstream from the dam. We report herein on tracking of salmon as they migrated back upstream to Bonneville Dam and our assessment of the use of fish trapped at the dam.

We set up receivers/antennas in 1996 in tributaries downstream from Bonneville Dam, at dams and tributaries in the lower Columbia River, at Priest Rapids Dam, at Ice Harbor and Lower Granite dams in the lower Snake River, and at the lower end of the Clearwater River and Snake River near Asotin, WA (Figure 1). Fish with transmitters returned to tributaries, dams, traps, and hatcheries upriver from Priest Rapids Dam and our uppermost sites in the Snake River, and we used recaptures of those fish to gain information about distribution of fish to tributaries.

Counts of spring chinook salmon at Columbia and Snake river dams were relatively low in 1996, and ranged from 18% of the 10-year average count at Priest Rapids Dam to 67% of the 10-year average at Bonneville Dam (Table 1). Counts of spring chinook salmon at Ice Harbor and Lower Granite dams were 29% and 24% of the 10-year average counts at those two dams.

The proportions of spring chinook salmon that were counted at Bonneville Dam in 1996, and later counted at Ice Harbor and Priest Rapids dams were below the previous 10-year averages (Table 2). The number of spring chinook salmon counted at Ice Harbor Dam was 11.6% of the count at Bonneville Dam -- less than half the 10-year average of 26.5%. At Priest Rapids Dam the number of spring chinook salmon counted was 4.7% of the count at Bonneville Dam, about one quarter the 10-year average of 17.6%.

Peak counts of spring chinook salmon were two to three weeks later than the 10-year average (1986 to 1995) in 1996 at Columbia River dams, and about two weeks later than average at Snake River dams (Figure 2). Flow and spill in the Columbia and Snake rivers were nearly double the prior 10-year averages (1986 to 1995, Figure 3). Water temperatures were 1 to 2 degrees C colder than the 10-year average and turbidity was higher than average and may have contributed to delays in migration, particularly in early May when Secchi-disk readings were less than 0.5 m (Figure 4). In 1996, 51,420 adult (jacks not included) spring chinook salmon passed Bonneville Dam before 1 June and peak counts (more than 2,000 salmon per day) were in mid May.

Although higher-than-average flow, spill, and turbidity continued at most dams through the summer in 1996, timing of the summer chinook salmon migration was similar to the 10-year average (Figure 2). Summer chinook salmon counts peaked from late June to early July at the Columbia River dams and in late June at the Snake River dams. Total summer chinook salmon counts in 1996 ranged from 61% to 75% of 10-year average counts (Table 1). Based on the dates for summer chinook salmon passage at dams as listed in the Annual Fish Passage Reports (Corps of Engineers 1997), just over 16,000 adult summer chinook salmon were counted at Bonneville Dam, 10,995 were counted at Priest Rapids Dam and 3,277 were counted in the Snake River passing Ice Harbor Dam (counts not adjusted for fallbacks).

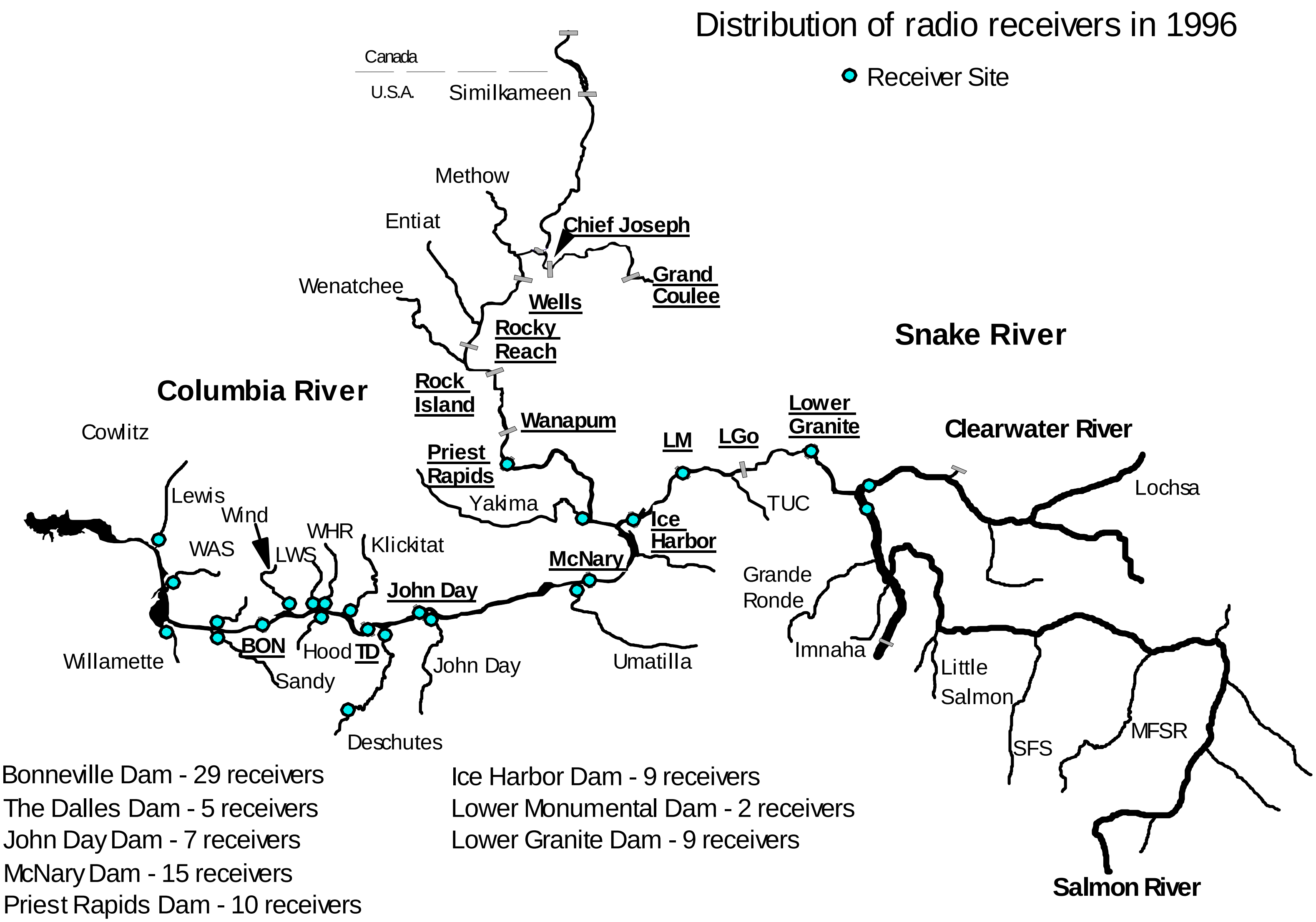


Figure 1. Location of radio receivers at dams and major tributaries within the Columbia River study area in 1996.

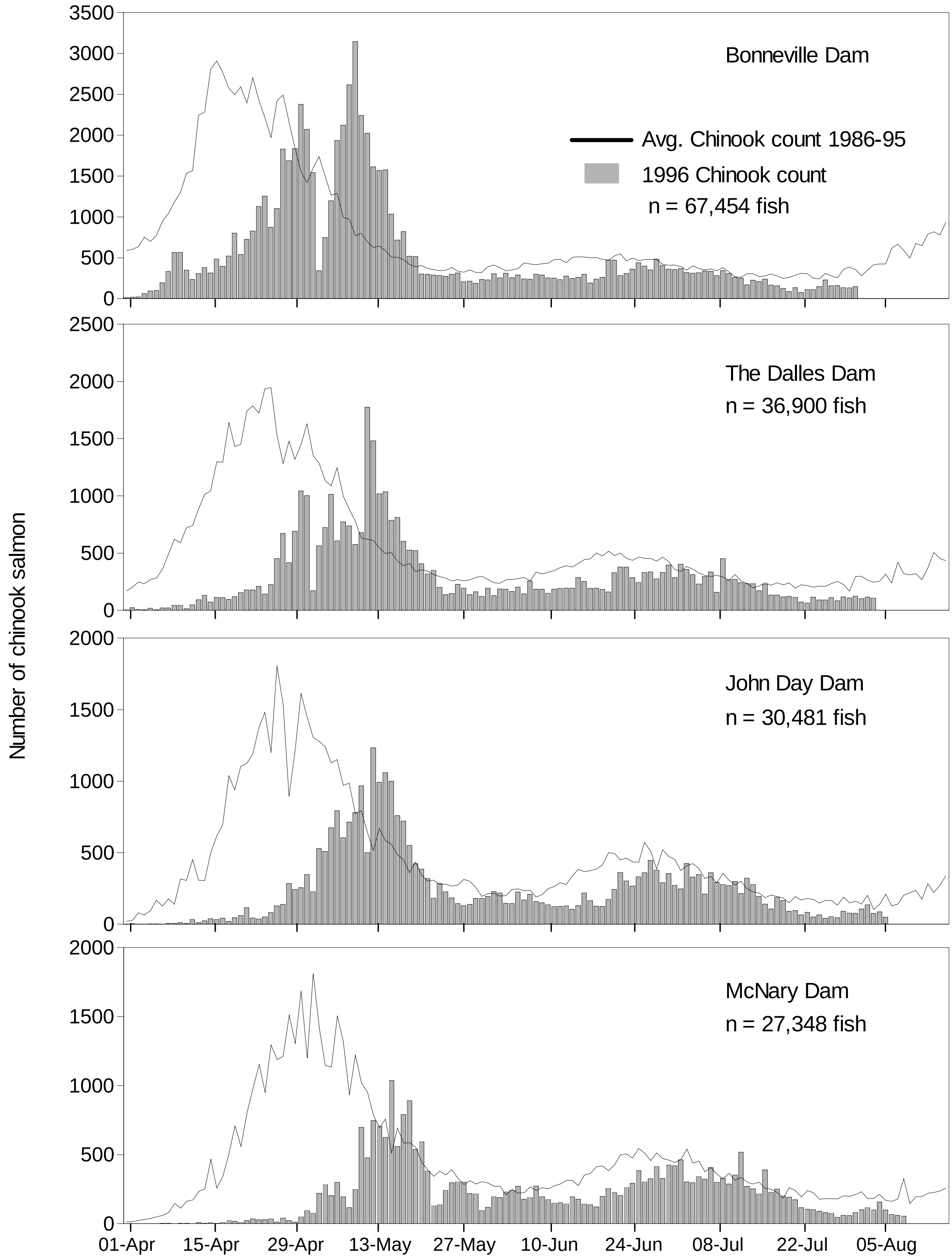


Figure 2. Number of spring and summer chinook salmon counted at Bonneville, The Dalles, John Day, McNary, Priest Rapids, Ice Harbor, and Lower Granite dams in 1996 with 10-year average counts (1986 to 1995).

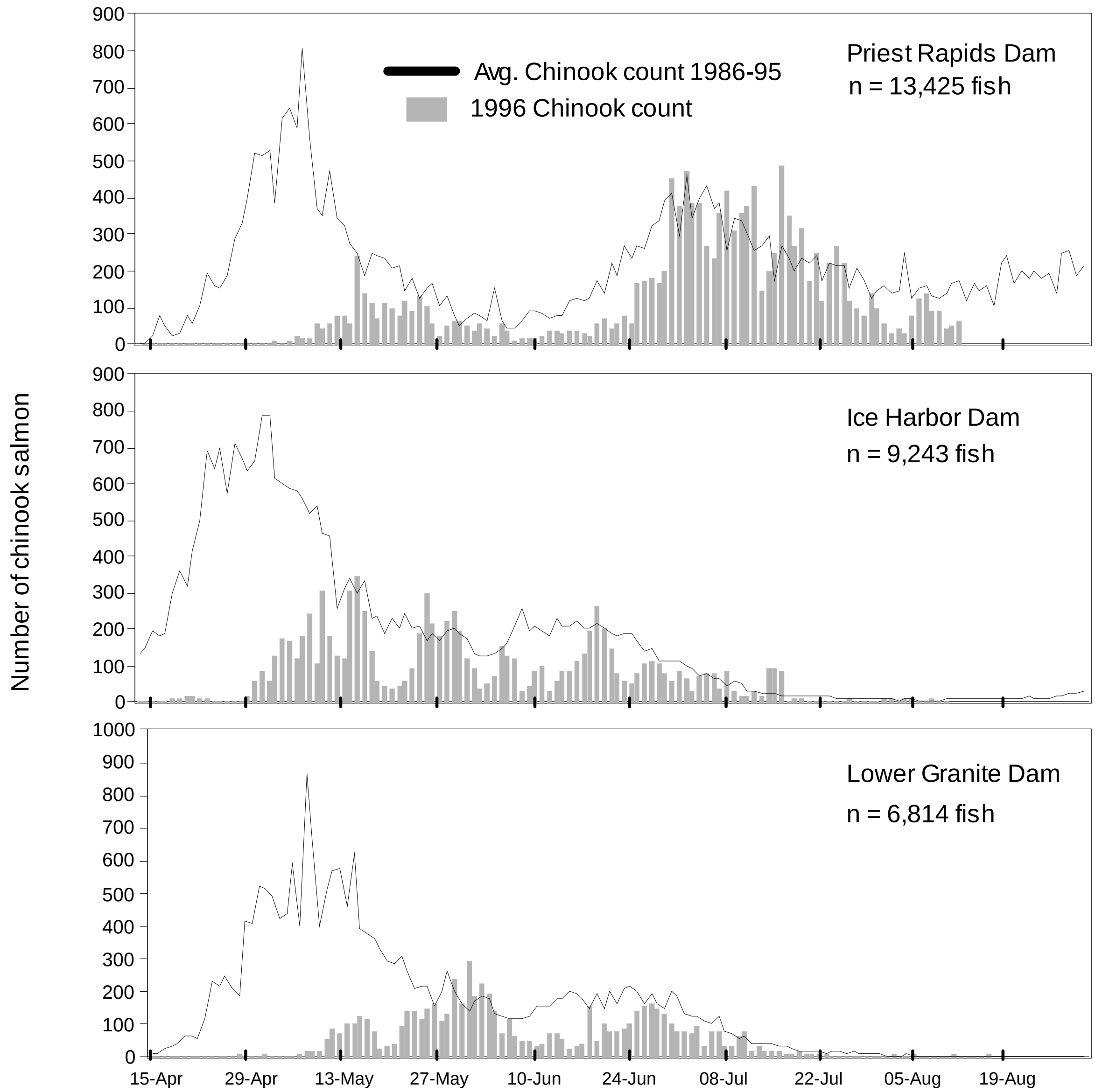


Figure 2. Continued.

Our study in 1996 was the first to use radio telemetry on a large scale (853 chinook salmon outfitted with radio transmitters) to assess the proportion of adult salmon that successfully passed dams in the lower Columbia River, and their passage times at the dams and through reservoirs. Cumulative passage times and minimum survivals from Bonneville Dam past multiple dams were also estimated. The influence of flow and spill on migration and fallback rates, relations between fallback and passage, final distributions for fallback and non-fallback salmon, and survival rates to major tributaries were estimated for salmon tagged in 1996.

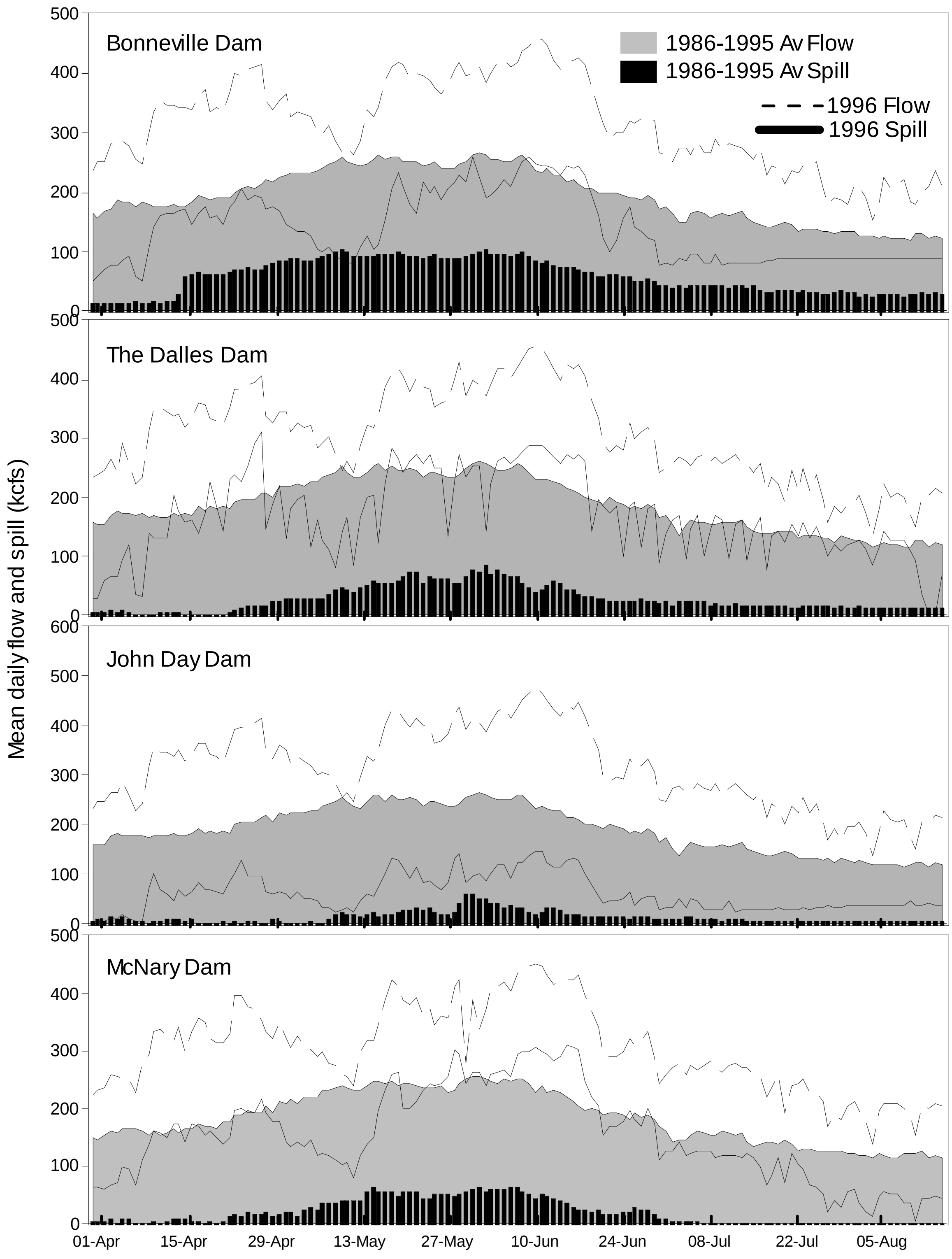


Figure 3. Mean daily flow and spill volumes at Bonneville, The Dalles, John Day, McNary, Priest Rapids, Ice Harbor, and Lower Granite dams in 1996 with 10-year averages (1986 to 1995).

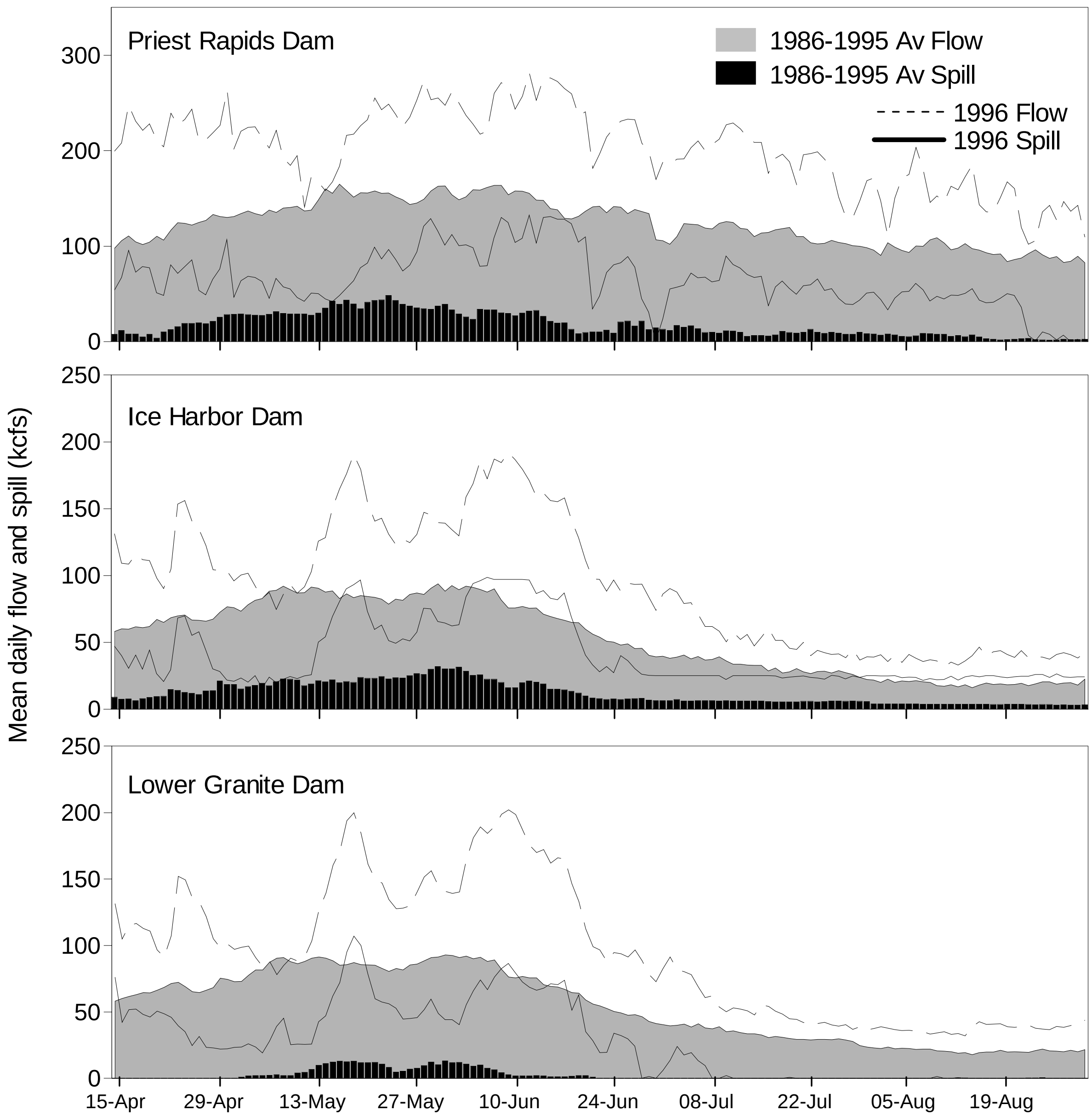


Figure 3. Continued

General Methods

Radio telemetry was the primary means of assessing the movements and passage rates of adult salmon in the Columbia River in 1996. In 1995, we began planning and installation of the telemetry setups that would be required at each dam and at the mouths of tributaries. We did not have enough radio receivers to fully outfit each dam in 1996 to monitor all fishway entrances and movements in the fishways. Priority dams for intensive study in 1996 were Bonneville, McNary, Priest Rapids, Ice Harbor, and Lower Granite dams. They were fully outfitted with receivers and antennas to monitor all fishway entrances and exits, as well as

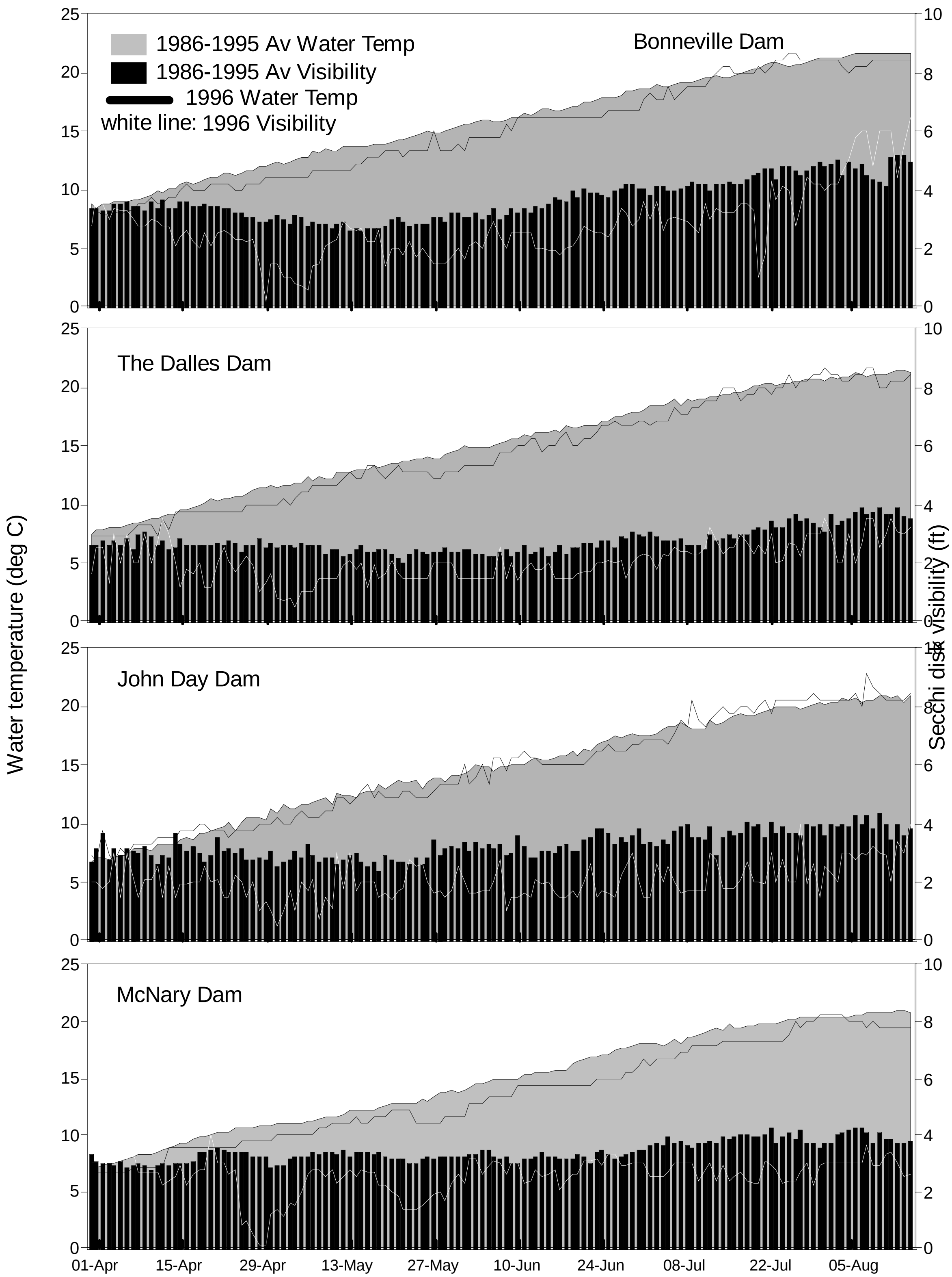


Figure 4. Mean daily water temperatures and Secchi disk visibility readings at Bonneville, The Dalles, John Day, McNary, Priest Rapids, Ice Harbor, and Lower Granite dams in 1996 with 10-year averages (1986 to 1995).

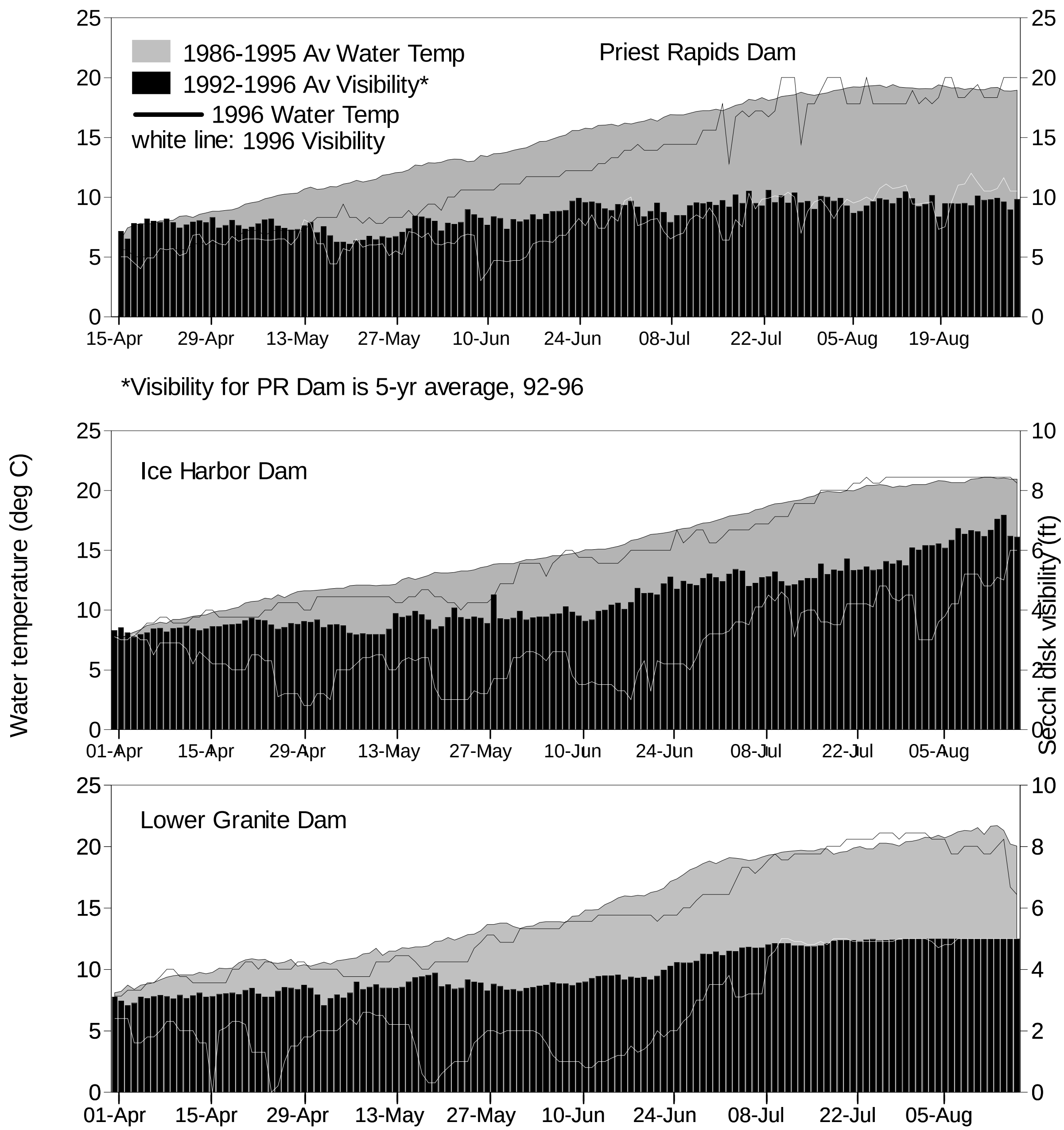


Figure 4. Continued.

the tailraces to determine when salmon with transmitters approached the dams (See Figure 1 and Table 3 for locations of receivers used in 1996). At the other dams, The Dalles, John Day, and Lower Monumental dams, receivers and antennas were installed at tailrace sites, top of the ladders, and at selected entrances. Passage of salmon with transmitters was not monitored in 1996 at Little Goose Dam, or at the mid Columbia River dams upriver from Priest Rapids.

We set up receivers and antennas on all major tributaries upstream from Bonneville Dam, and in selected

Table 1. Adult spring and summer chinook salmon counted at main stem dams in 1996, the 10-year mean count (1986 to 1995) and the 1996 counts as a percentage of the 10-year mean. Data from weekly Fish Passage Center reports.

	Spring chinook		Summer chinook		Spring and summer chinook	
Dams	1996 count	Percent of 10-year mean	1996 count	Percent of 10-year mean	1996 count	Percent of 10-year mean
Bonneville	51,493	67	16,034	69	67,527	67
The Dalles	23,877	47	13,023	66	36,900	52
John Day	18,651	47	11,830	73	30,481	54
McNary	14,373	36	13,300	74	27,673	48
Ice Harbor	5,973	29	3,277	69	9,250	37
Lower Granite	4,215	24	2,608	61	6,823	32
Priest Rapids	2,430	18	10,870	75	13,300	47

Table 2. Percentages of spring and summer chinook salmon counted at Bonneville Dam that were subsequently counted at Ice Harbor and Priest Rapids dams in 1996 and during the previous (1986-1995) 10-year period.

	Ice Harbor Dam		Priest Rapids Dam	
	Count at dam	Percent of Bonneville	Count at dam	Percent of Bonneville
10-Year average counts				
Spring chinook salmon	20,373	26.5	13,544	17.6
Summer chinook salmon	4,724	20.3	14,493	62.2
Spring and summer combined	25,097	25.0	28,298	28.2
1996 counts				
Spring chinook salmon	5,973	11.6	2,430	4.7
Summer chinook salmon	3,277	20.4	10,870	67.8
Spring and summer combined	9,250	13.7	13,300	19.7

tributaries downstream from the dam (Figure 1 and Table 3). Receivers/ antennas set up on the tributaries were near the mouths, but far enough upstream so that transmitter signals from fish in the Columbia or Snake rivers would not be picked up and recorded. At some tributaries we installed receivers/antennas upstream or downstream from the tributary mouths to monitor salmon with transmitters as they approached and proceeded upstream past a tributary.

Receiver and Antenna Outages

During 1996, individual sequentially scanning receivers (SRX) and Yagi antennas installed at tailrace sites down river from dams operated satisfactorily 81.4% to 97.9% of the time (mean of 91.0%, Table 4). SRX/DSP (SRX

Table 3. Location of receivers at dams and tributaries in 1996, with site codes, number and type of aerial (A) and underwater (U) antennas at each site, description of site, and river kilometers from Columbia River mouth for some sites.

Location	Site Code	Antennas	Type	Site description
Bonneville Dam	BO	1	A	Tailrace, south side
	2BO	1	A	Tailrace, north side
	3BO	1	A	Downstream end of navigation lock
	4BO	3	U	Powerhouse 1, south end entrances
	5BO	3	U	Powerhouse 1, sluice gates
	6BO	6	U	Powerhouse 1, sluice gates
	7BO	4	U	Powerhouse 1, sluice gates
	8BO	5	U	Powerhouse 1, sluice gates
	9BO	3	U	Powerhouse 1, north end entrances
	ABO	1	U	Top of Bradford Island ladder
	BBO	4	U	South end of spillway ladder entrance
	CBO	4	U	North end of spillway ladder entrance
	DBO	7	U	Powerhouse 2, south shore entrances
	EBO	5	U	Powerhouse 2, orifice gates
	FBO	4	U	Powerhouse 2, orifice gates
	GBO	5	U	Powerhouse 2, orifice gates
	HBO	5	U	Powerhouse 2, orifice gates
	JBO	4	U	Powerhouse 2, orifice gates
	KBO	5	U	Powerhouse 2, orifice gates
	LBO	5	U	Powerhouse 2, north shore entrances
	MBO	5	U	North shore ladder transition pool
	NBO	4	U	North shore ladder and transition pool
	OBO	3	U	Washington ladder/UMT channel junction
	PBO	1	U	Top of Washington shore ladder
	QBO	3	U	Top of navigation lock
	RBO	1	A	Spillway forebay, facing north
	SBO	1	A	Spillway forebay, facing south
	TBO	1	U	Powerhouse 1, ice and trash sluiceway
	UBO	1	U	Powerhouse 2, ice and trash sluiceway
The Dalles Dam	1TD	1	A	Tailrace, south side
	2TD	1	A	Tailrace, north side
	3TD	1	U	Oregon shore ladder, east entrance
	4TD	3	U	Top of Oregon shore ladder
	5TD	1	U	Top of Washington shore ladder
John Day Dam	1JD	1	A	Tailrace, south side
	2JD	1	A	Tailrace, north side
	3JD	5	U	Oregon shore ladder and transition pool
	4JD	2	U	Oregon shore ladder, down from diffuser
	5JD	2	U	Oregon shore ladder, up from diffuser
	6JD	1	U	Top of Oregon shore ladder
	7JD	1	U	Top of Washington shore ladder
McNary Dam	1MN	1	A	Tailrace, south side
	2MN	1	A	Tailrace, north side
	3MN	3	U	Oregon shore ladder entrance
	4MN	5	U	Oregon shore ladder transition pool

Table 3. Continued.

Location	Site code	Antennas	Type	Site description
	5MN	4	U	Orifice gates
	6MN	6	U	Orifice gates
	7MN	6	U	Orifice gates
	8MN	6	U	Orifice gates
	9MN	5	U	Orifice gates
	AMN	5	U	Orifice gates
	BMN	4	U	North powerhouse entrance
	CMN	3	U	Washington shore ladder entrance
	DMN	3	U	Washington shore ladder transition pool
	EMN	1	U	Top of Oregon shore ladder
	FMN	1	U	Top of Washington shore ladder
Priest Rapids Dam	1PR	1	A	Tailrace, east side
	2PR	1	A	Tailrace, west side
	3PR	4	U	East shore ladder transition pool
	4PR	5	U	East shore ladder entrance
	5PR	5	U	Orifice gates
	6PR	6	U	Orifice gates
	7PR	6	U	Orifice gates
	8PR	5	U	Orifice gate, West powerhouse entrance
	9PR	1	U	Top of East shore ladder
	APR	1	U	Top of West shore ladder
Ice Harbor Dam	1IH	1	A	Tailrace, north side
	3IH	4	U	South shore ladder entrance
	4IH	4	U	Orifice gates
	5IH	4	U	Orifice gates
	6IH	4	U	Orifice gates
	7IH	4	U	Orifice gate, north powerhouse entrance
	8IH	4	U	North shore entrance, transition pool, top
	9IH	2	U	Top of south shore ladder
	TIH	5	U	South shore ladder transition pool
	1CHAR	1	A	Forebay, 3 km upstream from dam
	2CHAR	1	A	Forebay, 3 km upstream from dam
Lower Monumental Dam	1LM	1	A	Tailrace, south side
Lower Granite Dam	1GR	1	A	Tailrace, south side
	2GR	4	U	South shore transition pool
	3GR	4	U	Orifice gates
	4GR	4	U	Orifice gates
	5GR	4	U	Orifice gates
	6GR	7	U	North powerhouse entrance
	7GR	2	U	North shore entrance
	8GR	1	U	Top of south shore ladder
	1WI	1	A	Forebay, 2 km upstream from dam
	2WI	1	A	Forebay, 2 km upstream from dam
Cowlitz River	CLZ	1	A	River mouth (RKM 112.0)
Kalama River	KLM	1	A	River mouth (RKM 118.4)
Lewis River	LWR	1	A	River mouth (RKM 141.4)

Table 3. Continued.

Location	Site code	Antennas	Type	Site description
Willamette River	WIL	1	A	River mouth (RKM 168.8)
Washougal River	WAS	1	A	River mouth (RKM 194.4)
Sandy River	SAN	1	A	River mouth (RKM 194.9)
Wind River	WIN	1	A	River mouth (RKM 249.2)
	WNM	1	A	River mouth (RKM 109.4)
Little White Salmon R.	LWS	1	A	River mouth (RKM 261.0)
	LWD	1	A	Down Columbia from LWS (RKM 260.1)
	LWU	1	A	Up Columbia of LWS (RKM 261.3)
White Salmon River	WHR	1	A	River mouth (RKM 270.9)
	WHD	1	A	Down Columbia from WHR (RKM 270.3)
	WHU	1	A	Up Columbia from WHR (RKM 271.0)
Hood River	HDR	1	A	River mouth (RKM 272.6)
Klickitat River	KTR	1	A	River mouth (RKM 290.7)
Deschutes River	DES	1	A	River mouth (RKM 328.9)
	DSM	1	A	Down Columbia from DES (RKM 327.1)
	SHF	1	A	Sherars Falls (RKM 396.3)
John Day River	JDR	1	A	River mouth (RKM 355.7)
Umatilla River	UMR	1	A	River mouth (RKM 467.1)
Walla Walla River	WWR	1	A	River mouth (RKM 506.0)
Yakima River	YAK	1	A	River mouth (RKM ~540)
Snake River	SNR	1	A	River mouth (RKM 762.3)
Clearwater River	CWR	1	A	River mouth (RKM 753.3)

connected to a digital scanning processor) receivers that were used to monitor the tops of ladders operated satisfactorily 85.2% to 99.9% of the time (mean of 93.1%), and SRX receivers at tributary mouths operated satisfactorily 89.6% to 100% of the time (mean 95.6%). Antennas and receivers that monitored entrances to fishways and within fishways operated at similar or slightly lower rates, but data from those receivers were typically not used for the passage studies in this report. Receiver outages occurred primarily because of power loss, receiver malfunction, vandalism, and full memory banks (Table 4). In a few additional cases, receivers were operating but were not accurately recording data or were recording data incompletely. Cut antenna wires, malfunctioning receivers or downloading errors accounted for most data gaps not explained by receiver outages (Table 5).

Outfitting Salmon with Transmitters

Radio transmitters were placed in 853 adult (no jacks) spring and summer chinook salmon trapped in the adult fish facility at Bonneville Dam in 1996 as they migrated upstream to natal streams or hatcheries. The salmon were transported to release sites at Dodson and Skamania Landings about 9.5 km downstream from Bonneville Dam. Tagging of adult spring and summer chinook salmon in 1996 began on 4 April and ended on 27 June, with ten days of tagging followed by four days without tagging (Figure 5).

Each day fish were tagged, the fish diversion weir in the Washington- shore ladder was lowered into place in the morning to divert fish from the main portion of the ladder into the fish lab via a short section of ladder. Salmon entered the lab into a large tank with two false weirs at the top of chutes that led to a

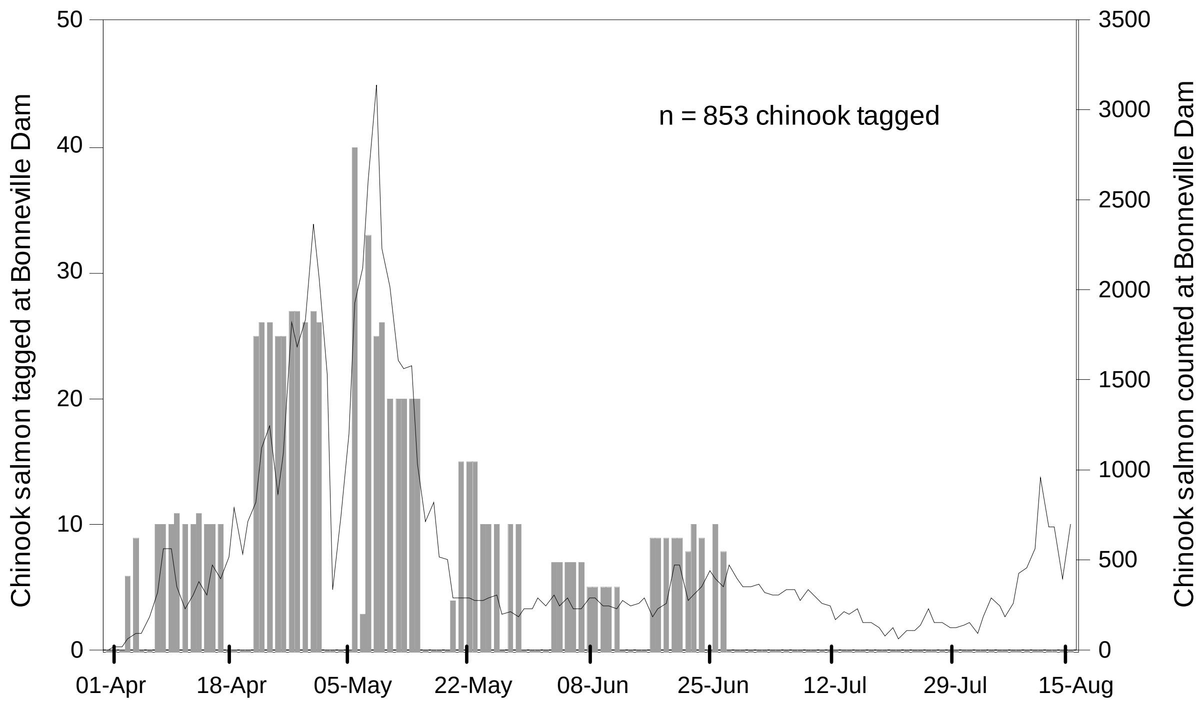


Figure 5. Number of spring and summer chinook salmon outfitted with radio transmitters at the Bonneville Dam adult trap, and the number counted passing the dam at the counting stations during the spring and summer migration in 1996.

channel back to the ladder or into anesthetic tanks. As salmon swam through the water flowing over the false weirs and slid down the chutes, a person would divert the fish into the anesthetic tank by operating a hydraulic gate if the fish was one we wanted to tag, otherwise the fish entered the channel that led back into the ladder. The only chinook salmon that were not diverted into the anesthetic tank were the smaller jacks. The trapping facility in the fish lab is one of the best on the river because the salmon were not handled by people until they were anesthetized and stress was thereby minimized. We did not lose any chinook salmon during tagging, transport, or release in 1996.

Tricane-methane-sulphonate (MS-222) was used to anesthetize the fish at a concentration of 100 mg/L. When the fish were anesthetized, they were placed in a wet plastic sleeve and moved to a tagging tank where their lengths were measured and they were examined for injuries, old scars, and fin clips. They were then outfitted with a transmitter that had been dipped in glycerin, by inserting it into the stomach through the mouth. The transmitter antenna was bent at the corner of the mouth and allowed to trail along the side of the fish. A secondary tag (VI, visual implant, numbered piece of plastic) was inserted into the clear tissue posterior to the eye (left usually), and a 1 mm-long piece of magnetic wire was inserted into the muscle near the dorsal fin to trigger the coded-wire detector at Lower Granite Dam. The fish were then placed in the wet sleeve and moved to the transport tank were they were held until released (usually less than 3 hours). The length of the trapping period each day was dependent on the number of salmon to be tagged and the number of fish moving up the ladder. If a small number of fish were to be tagged the fish might be caught in the first 1-2 hr of trapping. When we tagged 40 or more fish in one day, we usually would get half the fish and transport them in the morning, and the other half in the afternoon. The transport tank was a 300 gal , insulated, fiberglass tank with a large trap door on the end of the tank for release of the fish, and air stones in the bottom to supply oxygen from bottles mounted on the side of the tank. An overhead crane in the fish lab was used to move the transport tank in and out of the lab. Once trapping was finished for the day, the diversion weir pickets were removed from the ladder and fish in the entry tank were allowed to proceed up the ladder.

Of 853 chinook salmon tagged in 1996, 703 were likely spring chinook salmon (tagged before June 1), and 150 were mostly summer chinook salmon (tagged after 1 June). During the period of tagging, 59,449 adult chinook salmon were counted passing Bonneville Dam, and we tagged about 1 in 70 of the fish (1.43%). For spring chinook salmon, 51,420 fish were counted and we tagged 1 in 73 (1.4%). During the summer migration (1 June to 31 July), 16,034 chinook salmon were counted at Bonneville Dam, and 1 in 107 (0.9%) were tagged. As in previous years, we outfitted with transmitters what we believe was a random sample of the adult chinook salmon by not selecting fish at the trap. Fish were tagged as they were trapped, and if they were a random sample of the run then we tagged a random sample of the run. We tagged all fish regardless of injury or fin clip. Fish designated spring or summer chinook salmon at Bonneville Dam kept those designations regardless of date of passage at upriver Dams.

In 1996, 217 chinook salmon outfitted with transmitters had adipose, ventral or a combination of fin clips and 636 had no clips; 74% of spring fish and 79% of summer fish did not have clips. Juvenile salmon of the year classes returning as adults in 1996 were not all fin clipped when released from Washington and Oregon hatcheries, but fish with coded-wire tags and for specific projects were fin clipped. Idaho fisheries personnel clipped fins (mostly adipose) on all juvenile chinook salmon released for seaward migration starting in 1993, with ventral fin clips for hatchery fish used to supplement wild stocks and adipose fin clips for production fish (ID, WA, OR fish personnel, pers. comm.). Of 114 spring and summer chinook salmon with transmitters that passed Lower Granite Dam in 1996, 48% had fin clips and 52% had no clips. The adipose-right-ventral fin clip combination was used on smolts released from Lookingglass Hatchery in 1994, and 16 of the fish outfitted with transmitters (13 in April, and 3 in May, 69.5 to 79.0 FL) had that clip. Twelve of the 16 adults (75%) with transmitters were recaptured at the Lower Granite trap and then transported by truck to Lookingglass Hatchery, and the other four were unaccounted for with last records in the lower Columbia River. Adult chinook salmon we outfitted with transmitters in 1996 were classified as 50.2% female and 49.8% male. Fork lengths of fish tagged ranged from 57.5 to 125 cm with a median length of 75 cm. Median fork ength was 74.5 cm for spring chinook salmon and 81.8 cm for summer chinook salmon (Figure 6). Chinook salmon with fin clips and those without clips had median fork lengths of 75.0 cm.

Table 4. Receiver outages and hours of operation at dams, tributaries and other fixed sites in 1996. * tailrace receiver; ** top-of-ladder receiver

Receiver Site	Total possible operation hours	Actual operation hours	Total outage hours	Percent in operation
Bonneville Dam				
1BO*	6,518	6,381	137	97.9
2BO*	6,531	6,348	165	97.5
3BO	6,514	6,408	106	98.4
4BO	6,512	6,318	194	97.0
5BO	6,512	6,479	33	99.5
6BO	6,464	6,045	419	93.5
7BO	6,512	6,400	112	98.3
8BO	6,512	6,364	148	97.7
9BO	6,468	6,339	99	98.5
ABO**	6,512	6,471	41	99.4
BBO	6,512	6,423	89	98.6
CBO	6,513	6,300	213	96.7
DBO	6,511	6,392	119	98.2
EBO	6,510	6,485	25	99.6
FBO	6,510	6,489	21	99.7
GBO	6,511	6,505	6	99.9
HBO	6,508	6,475	33	99.5
JBO	6,510	6,359	151	97.7
KBO	6,510	6,449	61	99.1
LBO	6,510	6,047	463	92.9
MBO	6,510	6,488	22	99.7
NBO	6,511	6,468	43	99.3
OBO	6,512	6,274	238	96.3
PBO**	6,227	6,114	113	98.2
QBO	6,512	6,398	114	98.2
RBO	6,416	6,320	96	98.5
SBO	6,416	6,407	9	99.9
TBO	3,996	3,996	0	100.0
UBO	4,065	3,276	789	80.6
The Dalles Dam				
1TD*	6,508	6,174	334	94.9
2TD*	3,508	2,969	539	84.6
3TD	5,911	5,162	749	87.3
4TD**	6,258	5,785	473	92.4
5TD**	6,457	5,984	473	92.7
John Day Dam				
1JD*	6,410	5,716	694	89.2
2JD*	6,407	6,163	244	96.2
3JD	6,487	6,187	300	95.4
4JD	6,487	5,856	631	90.3
5JD	6,487	6,078	409	93.7
6JD**	6,485	6,111	374	94.2
7JD**	6,463	6,228	235	96.4
McNary Dam				
1MN*	6,485	6,278	207	96.8
2MN*	6,286	5,225	1061	83.1
3MN	6,480	5,879	601	90.7

Table 4. Continued.

Receiver Site	Total possible operation hours	Actual operation hours	Total outage hours	Percent in operation
4MN	6,482	5,663	819	87.4
5MN	6,482	5,841	641	90.1
6MN	6,482	5,989	493	92.4
7MN	6,446	5,615	831	87.1
8MN	6,479	6,087	392	93.9
9MN	6,482	5,691	791	87.8
AMN	6,482	5,984	508	92.2
BMN	6,281	5,525	756	88.0
CMN	6,483	5,580	903	86.1
DMN	6,483	5,494	989	84.7
EMN**	6,480	5,729	751	88.4
FMN**	6,483	5,969	514	92.1
Priest Rapids Dam				
1PR*	4,821	4,388	433	91.0
2PR*	4,800	3,907	893	81.4
3PR	2,614	2,121	493	81.1
4PR	2,614	2,183	431	83.5
5PR	2,518	2,179	339	86.5
6PR	2,617	2,171	446	83.0
7PR	2,619	2,077	542	79.3
8PR	2,618	5,169	449	82.8
9PR**	4,824	4,109	715	85.2
APR**	4,796	4,239	557	88.4
Ice Harbor Dam				
1IH*	6,054	5,425	629	89.6
3IH	1,894	1,892	2	99.9
4IH	1,895	1,894	1	99.9
5IH	1,898	1,896	2	99.9
6IH	1,900	1,769	131	93.1
7IH	1,902	1,901	1	99.9
8IH**	6,012	5,824	188	96.9
9IH**	6,029	5,891	138	97.7
TIH	1,616	1,582	34	97.9
1CHAR	1,160	1,153	7	99.4
2CHAR	1,160	1,159	1	99.9
Lower Monumental Dam				
1LM*	1,582	1,495	87	94.5
Lower Granite Dam				
1GR*	5,766	4,956	810	86.0
2GR*	5,781	5,285	496	91.4
3GR	5,898	5,887	11	99.8
4GR	5,900	5,898	2	99.9
5GR	5,901	5,900	1	99.9
6GR	6,441	5,525	916	85.8
7GR	5,906	5,903	3	99.9
8GR**	6,105	6,101	4	99.9
1WI	1,496	1,221	275	81.6
2WI	2,307	1,609	698	69.7

Table 4. Continued.

Receiver Site	Total possible operation hours	Actual operation hours	Total outage hours	Percent in operation
Tributaries				
Cowlitz (CLZ)	3,121	3,113	8	99.7
Kalama (KLM)	3,120	3,119	1	99.9
Lewis (LWR)	3,114	3,112	2	99.9
Willamette (WIL)	3,398	3,159	239	93.0
Washougal (WAS)	5,711	5,130	581	89.8
Sandy (SAN)	6,046	5,705	341	94.4
Wind (WIN)	6,491	5,871	620	90.4
WNM	3,970	3,654	316	92.0
L. Wh. Salmon (LWS)	6,383	5,719	664	89.6
LWD	3,993	3,820	173	95.7
LWU	3,991	3,989	2	99.9
White Salmon (WHR)	6,491	6,047	444	93.2
WHD	3,947	3,690	257	93.5
WHU	3,968	3,732	236	94.1
Hood (HDR)	6,588	5,953	635	90.4
Klickitat (KTR)	6,560	5,908	652	90.1
Deschutes (DES)	6,559	6,305	254	96.1
DSM	3,893	3,892	1	99.9
SHF	3,895	3,893	2	99.9
John Day (JDR)	6,315	5,921	394	93.8
Umatilla (UMR)	996	996	0	100.0
Walla Walla (WWR)	6,445	3,516	2929	54.6
Yakima (YAK)	6,447	6,097	350	94.6
Snake (SNR)	4,998	4,953	45	99.1
Clearwater (CWR)	5,412	5,412	0	100.0

Fifty-two percent of the 855 salmon tagged had no descaling, 39% less that 10%, 8% were 10-25% descaled, and 1% were more than 25% descaled. We recorded the prevalence of injuries on the heads of the fish and 92% had none, 2% had scrapes, 4% had skinned areas, and less than 1% had fungus, cuts, or eye injuries. Thirty-six percent of the fish had no marks from marine mammals, 51% had fresh scrapes on their bodies, and 13% had fresh bite injuries. Only 1% of the fish had what we thought were gill net marks.

We used a 7-volt transmitter developed and supplied by Lotek Engineering that transmitted a digitally coded signal every 5 s that included the frequency and code of the transmitter. The code set that we used allowed us to monitor up to 170 fish on each frequency. Transmitters were powered by a lithium battery and had a rated operating life of 270 d, but usually lasted a year or more. Transmitters used in chinook salmon were cylindrical, 80-mm long by 16-mm in diameter and had a 47-cm long Antenna.

Monitoring Fish Movements

Salmon with transmitters were monitored by use of fixed-site radio receivers at each dam, at the mouths of major tributaries, and by mobile trackers in areas not covered by fixed-site antennas. Additional information was collected at upriver dams, traps and weirs and from fishers that returned transmitters.

Table 5. Dates, duration and explanation for gaps in data collection by receivers and antennas not accounted for by receiver outages (Table 4).

Location	Start Date	End Date	Duration	Explanation
Bonneville Dam				
CBO-Antenna 2	25-Apr	1-May	7	Log damage
4BO-Antenna 1	?	9-May	?	Log damage
DBO	17-Apr	1-Jun	44	Defective receiver
EBO	25-Jun	25-Jun	<1	Maintenance
FBO	25-Jun	27-Jun	2	Maintenance
7BO-Antenna 4	16-Aug	27-Aug	11	Antenna cut
BBO-Antenna 2	1-Sep	2-Oct	31	Antenna cut
The Dalles Dam				
5TD	29-Sep	4-Oct	5	Antenna pulled out of water
2TD	?	15-Nov	?	Bad connection
John Day Dam				
4JD	3-Sep	13-Sep	10	Download error
McNary Dam				
BMN	10-May	15-May	5	Download error
EMN	7-Jul	12-Aug	36	Defective receiver
1MN	20-Jul	12-Aug	23	Antenna cut
3MN	?	18-Oct	?	Defective receiver
Ice Harbor Dam				
9IH	28-Apr	29-Apr	1	Defective receiver
9IH	6-May	6-May	<1	Defective receiver
9IH	24-May	28-May	4	Defective receiver
4IH-Antenna 1	?	12-Jun	?	Broken antenna
5IH-Antenna 1	?	12-Jun	?	Broken antenna
Lower Granite Dam				
5GR-Antenna 1	?	22-Nov	?	Antenna cut

In addition, because of the concern that fish from the Washington- shore ladder might not be representative of the total run passing the dam, we tracked salmon with transmitters by boat from the release sites back up to the dam. We wanted to know if they mostly returned to pass the dam via the same ladder or if location of passage was random.

SRX receivers were used with Yagi antennas to determine when fish first entered the tailrace area of a dam. Digital spectrum processors (DSP) added to SRX receivers could simultaneously monitor several frequencies and antennas, and were particularly helpful in monitoring movements of adults into and through fishways at the dams. SRX/DSP receivers were connected to underwater antennae made of coaxial cable and were positioned near all fishway entrances, exits, and inside fishways at dams where fish were monitored intensively.

We also installed SRX receivers connected to Yagi antennas near the mouths of most major tributaries to the Columbia River, from the Cowlitz River 225 km downstream from Bonneville Dam to Priest Rapids Dam, at the mouth of the

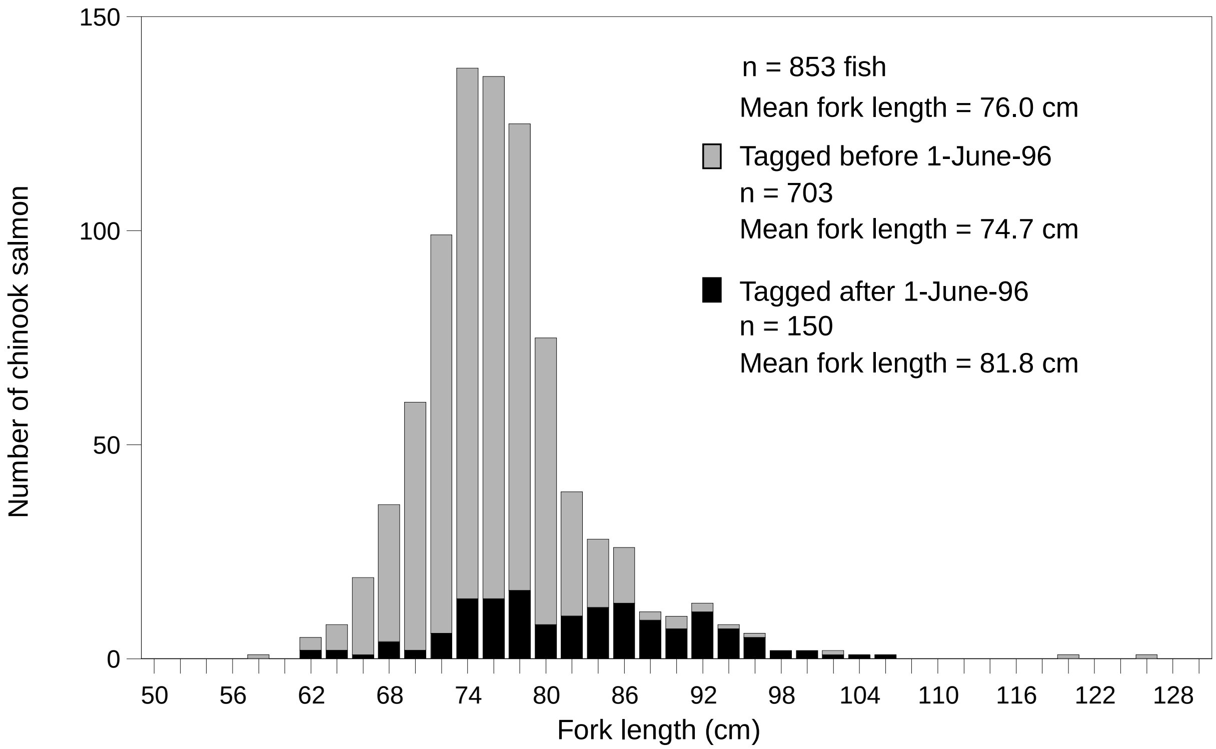


Figure 6. Length frequency distribution of spring and summer chinook salmon outfitted with transmitters at the Bonneville adult trap in 1996.

Clearwater River (Figure 1). For more details on receiver and antenna installation and the evolution of monitoring techniques for the adult passage project, see Bjornn et al. (1998).

Three trucks were outfitted with 4-element Yagi antennas and SRX receivers to track fish in areas not covered by fixed-site receivers. Two boats were similarly outfitted to facilitate mobile tracking in reservoirs, as well as the free-flowing section of the Columbia River between Pasco and Priest Rapids Dam. In 1996, sections of the lower Columbia River were mobile-tracked approximately once each week during most of the spring and summer chinook salmon migration. Segments of the Wind, White Salmon and Little White Salmon rivers were also mobile-tracked every 1 to 2 weeks. The Washington Department of Fish and Wildlife (WDFW) mobile-tracked the Tucannon River frequently throughout the migration and also tracked segments of the lower Snake River. We tracked the Clearwater, Salmon and Upper Snake rivers at least once during the summer of 1996.

Data Collection and Processing

Members of the study team downloaded data from receivers into portable computers periodically, with the frequency depending on the number of fish passing a site. Some sites were downloaded daily during the peak of the run, and some every two weeks. Each night files of downloaded data were transmitted to a computer at the NMFS lab in Seattle and added to databases. Records consisted of transmitter frequency (channel), code, date, time, power of signal received, and site. In 1996, databases were created for all the records of each fish at each dam and each species. After each day of tagging, a member of the tagging crew transmitted a file with records of fish tagged that day to the Seattle computer. When records were uploaded to the databases, the records were evaluated and good records added to the databases, and bad records were placed in a bad-record table. Bad records were those with channels and codes for fish that had not been released. As the season progressed, files of data for each dam were sent to the University of Idaho for coding by study team members.

Coding of the records consisted of going through all the records for a fish at a dam and assigning codes to identify fish activity. For example, the first record of a fish at the tailrace site downstream from a dam was coded as a ‘F1’, and the last record at the tailrace site was coded as a ‘L1’. Similarly each approach and entry into the fishways was coded as were exits back into the tailrace and exits from the top of ladders. When all the fish had been coded for a dam, the coded records were returned to Seattle and added to the databases. We had a program written to assist in the coding that incorporated a decision tree that a coder would use in coding records manually. The program speeded up the coding process, but there was no substitute for evaluation of fish behavior by an experienced coder.

When all fish had been coded at each dam, all coded records for each salmon with a transmitter were combined into a file with records from tributary receivers, records of fish found by mobile trackers, and records of fish that were recaptured at weirs, hatcheries, spawning grounds, or in fisheries. Records in the file that had not been previously coded were then coded to create the ‘general migration’ file, the file that contained most of the data presented in this report.

Above, we referred to records of fish found by mobile trackers, and of those of fish recaptured in fisheries, at adult traps, weirs and hatcheries, and those recovered in spawning areas. Separate data files were created for mobile track records and recapture records at the University of Idaho, and data in those files were added to the databases in Seattle prior to coding the general migration file.

Evaluation of the Use of Chinook Salmon Trapped at Bonneville Dam

Introduction

There was a concern that adult salmon and steelhead trapped in the Adult Fish Facility as they migrated up the Washington-shore fishway might not be representative of the runs or may not behave the same as naive fish. For example, if disproportionate numbers of the salmon that used the Washington-shore ladder were destined for Washington-shore tributaries (Wind, Little White Salmon, White Salmon, and Klickitat rivers) there would be an under-representation of fish destined for south-shore tributaries (Hood, Deschutes, John Day, and Umatilla rivers) and of fish destined for the mid-Columbia and Snake rivers. To evaluate that concern, we monitored the migration paths of adult spring chinook salmon and steelhead with transmitters as they returned back to Bonneville Dam from the release sites, and the approaches, entries, and ladders used to pass the dam.

Adult salmon and steelhead were collected at Bonneville Dam, outfitted with transmitters and released at the two sites (one on either shore) about 9.5 km downstream from the dam. The goals of the study were to determine routes used by chinook salmon as they migrated in the river, and if salmon trapped from the Washington-shore fishway returned in disproportionate numbers to that fishway.

Methods

From 4 April to 27 June 1996, 853 spring and summer chinook salmon were outfitted with transmitters and released in equal numbers at the north-shore (Skamania Landing, WA) and south-shore (Dodson, OR) release sites (Figure 7). Following release, salmon were tracked as they migrated upstream using a boat outfitted with a radio receiver and aerial antenna. Fish were located by moving the boat short distances up and downstream in the vicinity of the fish, and by rotating the antenna until the power of the signal from a transmitter was maximum. Fish locations and times were noted on maps of the stretch of river downstream from Bonneville Dam (Figure 7). Typically, several fish were monitored each day by repeatedly locating fish as they progressed in their migration back to Bonneville Dam.

Radio receivers connected to aerial antennas, one on each shore, were used to determine when chinook salmon with transmitters entered the tailrace of Bonneville Dam (Figure 7). The south-shore antenna was located 1.1 km downstream from powerhouse 1 and the north-shore antenna was 3.2 km downstream from powerhouse 2. Underwater coaxial cable antennas were used to monitor when and where salmon approached and entered fishway entrances at powerhouse 1, the spillway, and powerhouse 2. A receiver and aerial antenna was also used to monitor fish that entered the tailrace portion of the navigation lock channel. Passage times were calculated from time of release until the salmon were first recorded on the tailrace receivers and were first recorded at a fishway entrance at the dam.

Results

A total of 104 chinook salmon with transmitters were tracked for at least a portion of their passage through the 9.5 km stretch of Columbia River between the release sites and Bonneville Dam. We were able to monitor the entire route of passage from release until they reached the dam for 44 of the 104 chinook salmon. Salmon tended to move upstream along the shorelines but some crossed the river at certain locations. Radio-tagged salmon did not preferentially return to the north-shore at Bonneville Dam in 1996.

In general, salmon that were actively migrating upstream remained close to the shorelines (Figure 8). Occasionally moving fish were located in the middle of the river channel, mostly in the section of river north of Pierce and Ives islands. This area was relatively shallow and slow-flowing compared to the main river channel south of the islands. Salmon moved from point of release until they reached Bonneville Dam along the same shore on which they were released (Figure 9), or they crossed the river to the opposite shore one or more times during their migration (Figures 10 and 11). Out of 104 salmon, 69 (66%) were known to have crossed the river at least once while returning to Bonneville Dam. Of those 69 fish, 51 crossed the river once, 15 crossed twice, and 4 fish crossed the river three times while being tracked. Most fish crossed the river in three general areas, near release sites, at the eastern end of Ives Island and near Moffett Creek, or at some point along the length of Hamilton

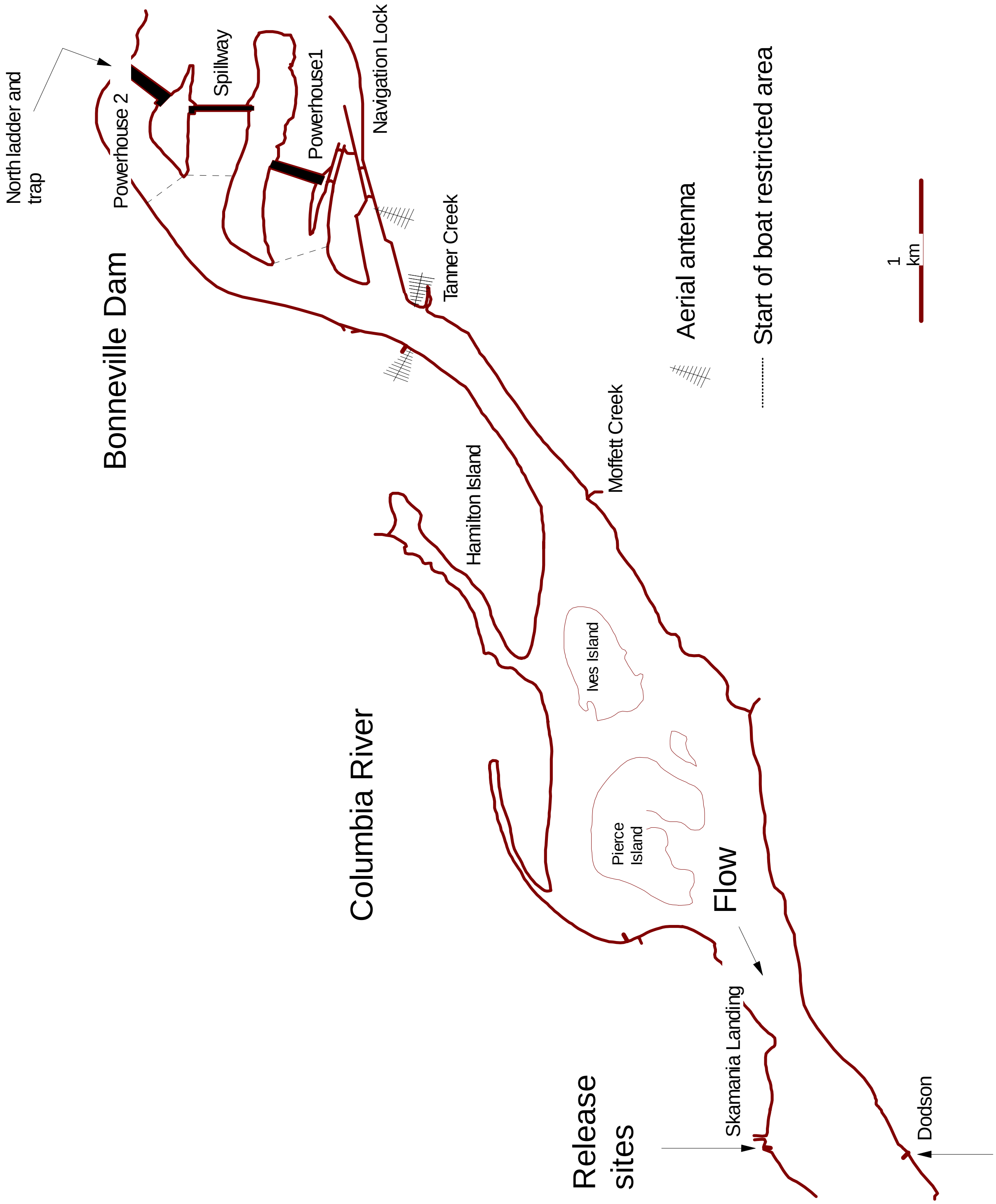


Figure 7. Columbia River downstream from Bonneville Dam where radio-tagged chinook salmon were tracked in 1996, showing location of north- and south-shore release sites and tailrace receivers. Restricted areas near Bonneville Dam, where salmon could not be tracked, are delineated with dashed Lines.

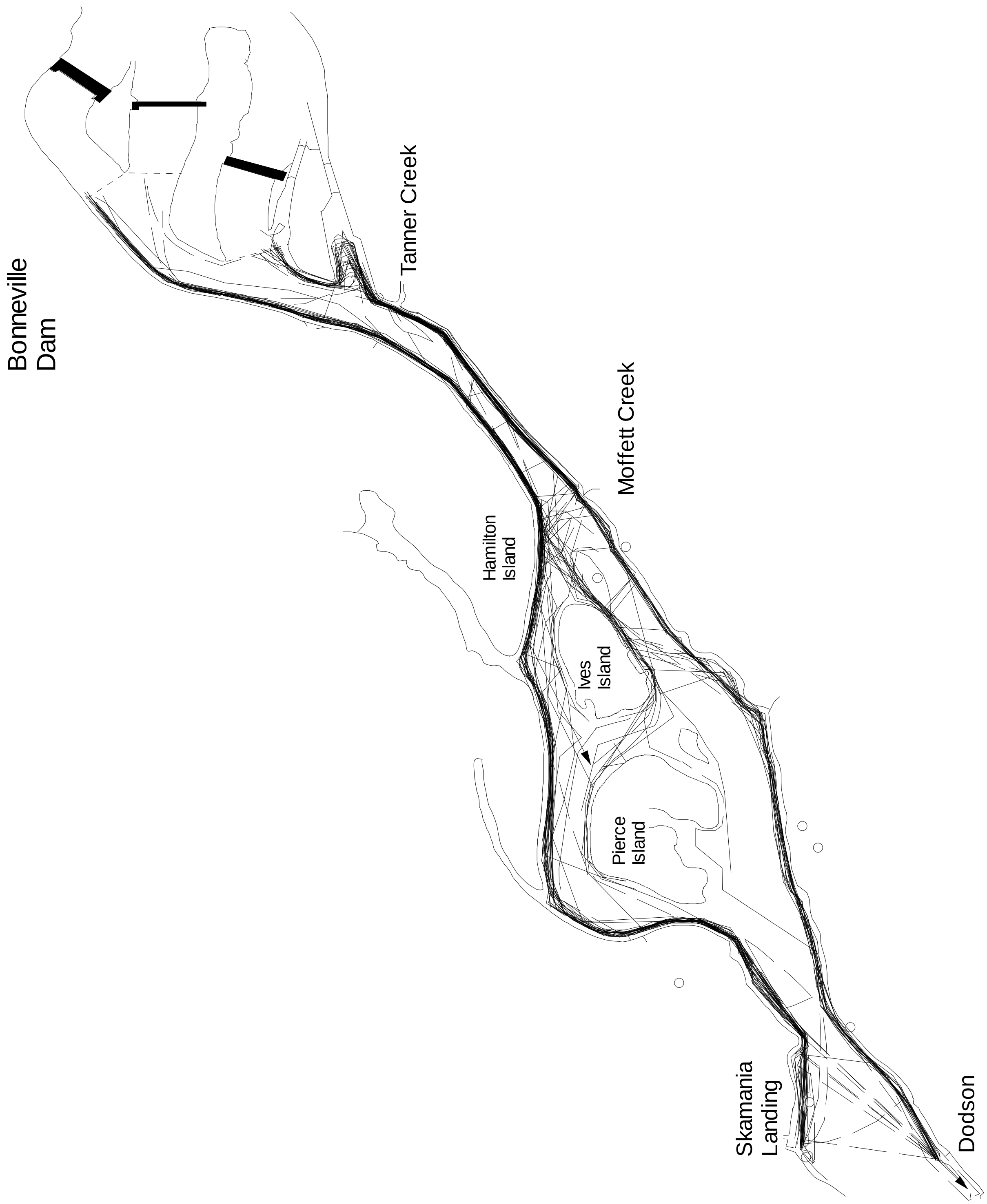


Figure 8. Composite of routes taken by radio-tagged chinook salmon tracked in the Columbia River downstream from Bonneville Dam in spring 1996.

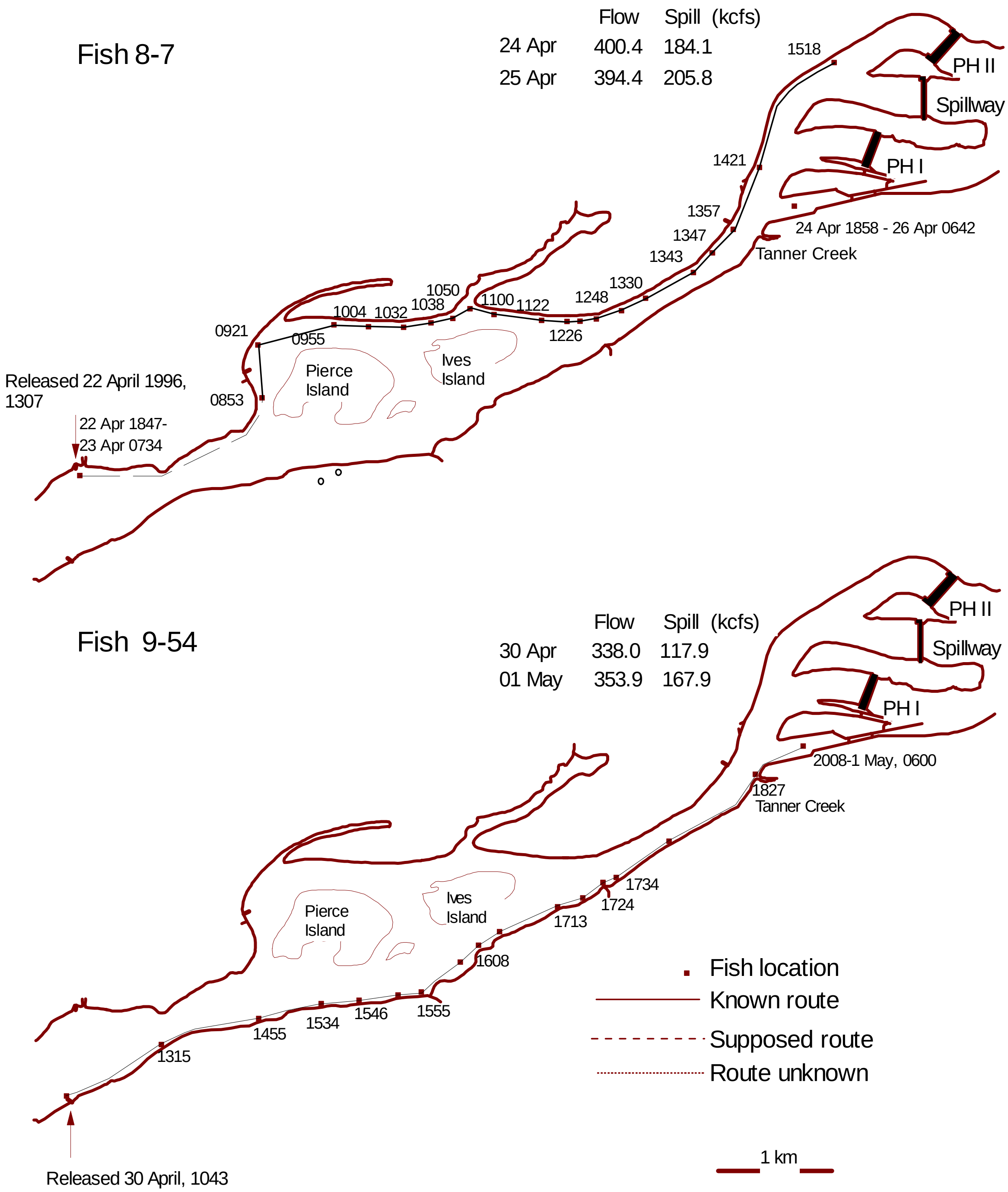
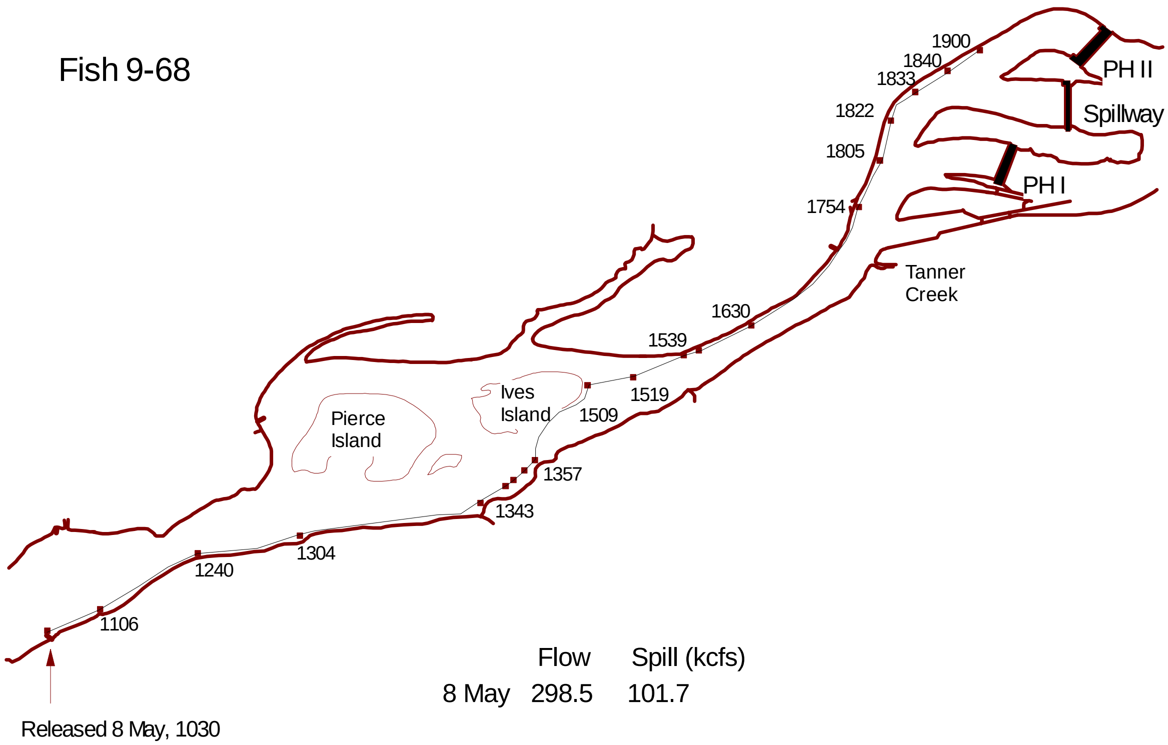


Figure 9. Examples of chinook salmon with transmitters that migrated from release on the north (top) and south (bottom) shores to Bonneville Dam without crossing the river. Times are shown to the side of fish locations. Fish are identified by channel-code of transmitter used.



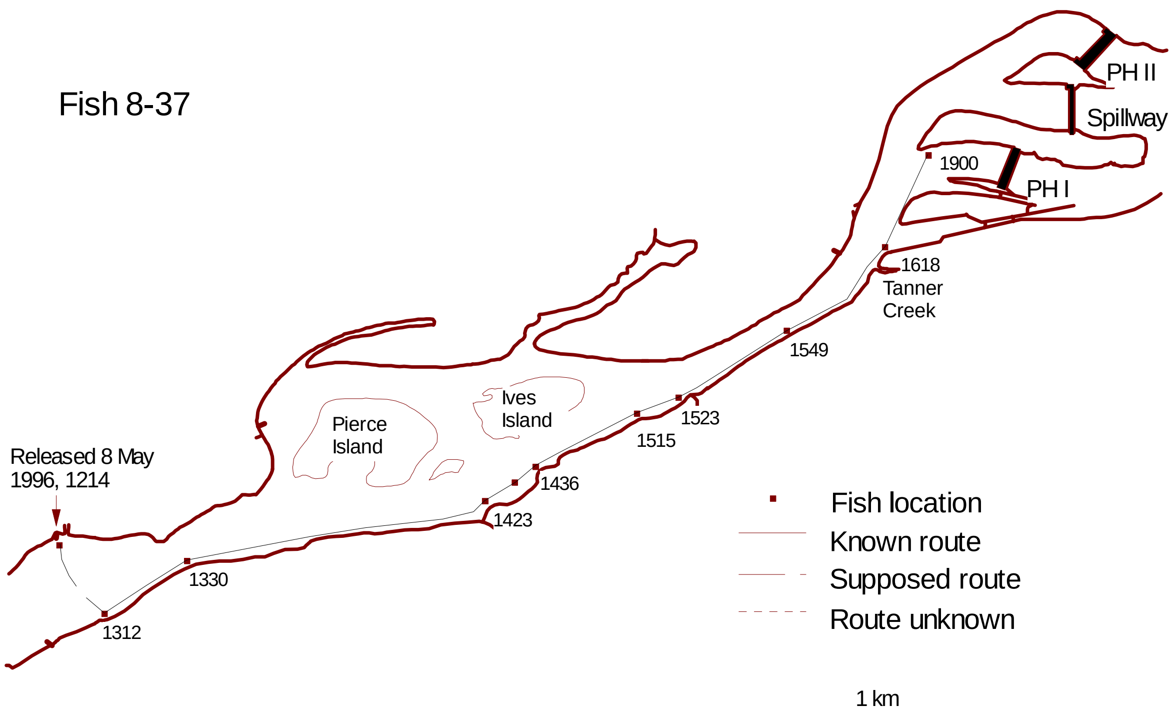


Figure 10. Examples of chinook salmon with transmitters that crossed river once between release reaching Bonneville Dam. Times are shown to the side of fish locations. Fish are identified by channel-code of transmitter used.

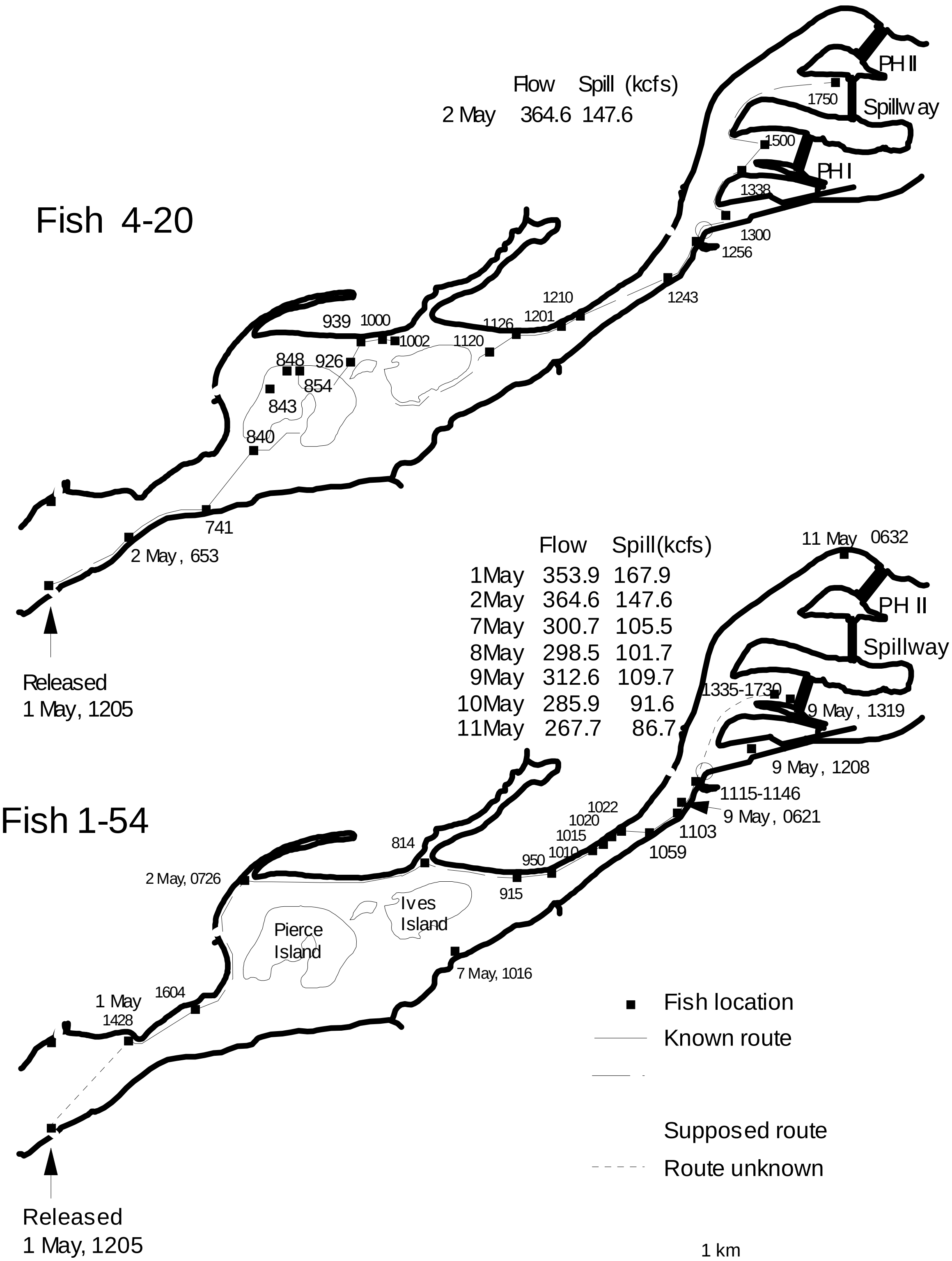


Figure 11. Examples of chinook salmon with transmitters that crossed river more than once between release and reaching Bonneville Dam. Times are shown to the side of fish locations. Fish are identified by channel-code of transmitter used.

Island (Figure 8). There were 23 river crossings that were known to have occurred but were not directly observed; fish were last tracked on one side of the river but were subsequently recorded at the dam on the opposite side of the river. Of the 75 river crossings observed, 46 (61%) were from the north shore to the south shore and 29 were from the south shore to the north shore. Transmitter signals were lost or became weak when the salmon crossed the river, an indication that the fish moved deeper, possibly following the river bottom, when crossing the river.

For the 104 salmon we mobile tracked by boat, 59 were released on the north shore and 45 were released on the south shore. At the tailrace receiver sites, 27 (26%) of the fish were first recorded on the north shore, 71 (68%) were first recorded on the south shore, and 6 fish were not recorded prior to their first approach to the dam. Fifty-five (53%) of the salmon first approached a fishway entrance at powerhouse 1, 10 (10%) at the spillway, 38 (36%) at powerhouse 2, and one fish first approached the dam at an unknown entrance. Where salmon eventually crossed the dam was equally divided between the north-shore (49%) and Bradford Island (48%) ladders. Three fish did not reascend the dam. Fifty-four (52%) of the fish we tracked were found in the tailrace portion of the navigation lock channel at least once while at Bonneville Dam.

Passage times for 97 of the salmon we tracked from release until their first record at the tailrace receiver sites were a median of 21.5 h and mean of 31.7 h (sd = 67.4 h). Passage times from release until first approach at the dam for 97 tracked salmon were a median of 25.5 h and mean of 48.1 h (sd = 83.1 h).

Behavior of the 853 spring and summer chinook salmon tagged at Bonneville Dam in 1996 was similar to that of 104 fish we tracked. Of the 853 salmon released, 247 (29%) were first recorded on the north-shore tailrace receiver, 495 (58%) were first recorded on the south-shore receiver, and 116 (13%) were not recorded on either tailrace receiver prior to their first approach at the dam. The distribution of first approaches at the dam was also similar for the tracked and entire groups, with 440 (51%) recorded at powerhouse 1, 47 (5%) at the spillway fishway entrances, 279 (33%) at powerhouse 2, and 92 fish with first approaches that we could not determine. For salmon that eventually crossed the dam, 353 (47%) used the north-shore ladder and 402 (53%) used the Bradford Island ladder. Of the 853 chinook salmon outfitted with transmitters in 1996, 408 (48%) were recorded in the tailrace portion of the navigation lock at least once.

Passage times for the main group of salmon with transmitters (706 salmon with data) were also similar to the tracked group of fish described above. From time of release until their first record at the tailrace receivers, passage times were a median of 18.9 h and mean of 27.0 h (sd = 41.5 h) for the larger group. Passage times from release until first approach at the dam for the 706 salmon were a median of 23.6 h and mean of 37.4 h (sd = 49.6 h).

Chinook salmon trapped from the Washington-shore fishway at Bonneville Dam, outfitted with transmitters, and released on both sides of the river 9.5 km downstream from the dam returned in a random pattern to the dam, not predominately to the Washington side of the river. More salmon entered the tailrace and approached Bonneville Dam from the south than north shore, but fish that eventually passed the dam used the Washington-shore and Bradford Island fishways about evenly. Fates of chinook salmon with transmitters after passage at Bonneville Dam will be discussed in later sections of this report.

Chinook salmon with transmitters predominately migrated near shore while returning to Bonneville Dam. Actual distances from shore and depths at which fish migrated were difficult to determine but were estimated at times based on the location of the boat when transmitter signals were maximal. Fish could not be seen from the boat while migrating, but signal strengths from transmitters remained relatively constant while the fish were moving. We believe most salmon swam mostly at depths between 1 and 10 m while actively migrating. Distance from shore at which salmon migrated varied and appeared to be related to depth. In shallow water, such as in the area between the north shore and Pierce and Ives islands, the salmon were found up to 100 m from shore. In deeper water, such as between Moffett and Tanner creeks along the south shore, salmon were often less than 10 m from shore.

Two-thirds of the salmon we tracked crossed from one shore to the opposite shore at least once while returning to Bonneville Dam. There were more river crossings from the north shore to the south shore than in the opposite direction, which explains why more of the tracked salmon entered the tailrace of the dam along the south shore even though more of the fish we tracked were released on the north shore of the river.

Chinook salmon migrated from release sites to the tailrace at a rate of about 9 km/d, based on median passage times. Migration rates have not previously been studied for chinook salmon in the lower Columbia River downstream from Bonneville Dam, but migration rates for chinook salmon were 13-35 km/d in the unimpounded sections of the Clearwater, Salmon, and Snake rivers (Bjornn and Peery 1992; Bjornn et al. 1998). Recovery from tagging and transport to the release site probably contributed to the slower migration rates we observed as the tracked fish returned to the dam.

Passage, Migration History, and Final Distribution of Chinook Salmon

Methods

In this report of the general migration of adult spring and summer chinook salmon, we classified passage at a dam as successful for any radio-tagged fish recorded at top-of-ladder receivers or at sites upriver from a dam, regardless of whether they subsequently fell back over a dam or their final destination was downstream from a dam. Times to pass a dam in this report were calculated from tailrace receiver sites (0.5 to 3.2 km downstream from each dam) to a fish's exit from the top of a ladder. Times were calculated from the first record on the first trip past the tailrace receiver to the last record at the top of a ladder for fish that were recorded at both sites. For 1996 chinook salmon, more specific aspects of passage at individual dams, such as time to approach a dam and enter fishways, fishway entrances used, movements within fishways, and behavior in and passage time through transition pools were reported in Bjornn et al. (2000a).

The percentage of adult spring and summer chinook salmon with transmitters that passed each dam successfully was calculated from the number released and the number known to have passed each dam. The number known to have passed a dam was determined primarily from records of fish passing receivers at the tops of ladders, but also included fish recorded at sites upriver from a dam because receivers at the tops of ladders were not 100% efficient. Fish that were not recorded at the top of a ladder, but were recorded at another site further upriver, were treated as successfully passing the dam, but they were not included in passage-time analyses for the dams where they were not recorded.

Passage at Dams

In 1996, 15 of the 853 chinook salmon outfitted with transmitters regurgitated their transmitters near the release site down river from Bonneville Dam. Of the remaining 838 salmon, 830 (99.0%) were known to have returned to the Bonneville tailrace and 809 (96.5%) were known to have reascended and passed the dam. Of the 838 chinook salmon that retained transmitters, 497 (59%) were known to have passed The Dalles, 377 (45%) passed John Day, 301 (36%) passed McNary, 120 (14%) passed Ice Harbor, 114 (13%) passed Lower Granite, and 113 (14%) passed Priest Rapids dams (Table 6). At all dams, the percentage of chinook salmon known to have passed tailrace and top-of-ladder receivers was slightly larger than the percentage recorded by receivers at those sites (Table 6). The difference between recorded and known-to-have-passed percentages ranged from 0.9% to 11.3% for tailrace receivers and from 0.8% to 7.6% for top-of-ladder receivers. The differences were inflated slightly because a few tagged chinook salmon were recaptured without transmitters and they were not recorded at one or more receiver sites along their migration route. Of these, eight were recaptured at the Lower Granite adult trap, but had their last telemetry records at Ice Harbor Dam or lower Columbia River dams. Five additional fish had telemetry records at Lower Granite Dam but were recaptured at the adult trap without transmitters. Three were recorded in lower Columbia River tributaries other than the Wind River, but were recaptured at Carson National Fish Hatchery, and two had their last telemetry records at Bonneville Dam but were recaptured at Wells Hatchery. All salmon with non-functional transmitters were included in the having passed number if they were recaptured upstream of a dam, but were not recorded on a ladder antenna at the dam.

Most salmon with transmitters that were known to have passed a dam's tailrace receiver eventually passed that dam. However, 10.1% of the fish known to have entered The Dalles tailrace, 10% that entered the Ice Harbor tailrace, 5.8% that entered the Priest Rapids tailrace and 2.5% that entered the Bonneville tailrace did not pass those dams. More than 98% of the fish known to have entered the John Day, McNary and Lower Granite tailraces passed those dams (Table 6). Failure of a significant number of salmon to pass The Dalles, Ice Harbor, and Priest Rapids dams after being recorded in the tailrace may not be unusual because of the large number of salmon produced in the Bonneville Dam pool tributaries, because Ice Harbor Dam is at a major confluence, and because Priest Rapids Dam is just

Table 6. Number of adult spring and summer chinook salmon released down river from Bonneville Dam, number that regurgitated transmitters, number and percentage of 838 fish that retained transmitters that were recorded at the tailrace and ladder receivers at each dam, and number and percentage of fish known to have passed tailrace and top of ladder receivers in 1996.

	Bonneville	The Dalles	John Day	McNary	Ice Harbor	Lower Granite	Priest Rapids
Chinook salmon released with transmitters							
Number	853	----	----	----	----	----	----
Number that regurgitated transmitters at or near the release site							
Number	15	----	----	----	----	----	----
Number and percentage chinook salmon recorded at tailrace receivers							
Number	781	458	355	243	96	78	116
Percent	93.2	54.7	42.4	29.0	11.5	9.3	13.8
Number and percentage known to have passed tailrace receivers							
Number	830	553	384	307	132	114	120
Percent	99.0	66.0	45.8	36.6	15.8	13.6	14.3
Percentage of those known to pass tailrace that were recorded at tailrace receivers							
Percent	94.1	82.8	92.4	79.2	73.3	68.4	96.7
Number and percentage tagged chinook salmon recorded at tops of ladders							
Number	795	433	358	295	103	86	111
Percent	94.9	51.7	42.7	35.2	12.3	10.3	13.3
Number and percentage of 838 known to have passed over dams							
Number	809	497	377	301	120	114	113
Percent	96.5	59.3	45.0	35.9	14.3	13.6	13.5
Percentage of those known to pass dams that were recorded at tops of ladders							
	98.3	87.1	95.0	98.0	85.8	75.4[a]	98.2
Number and percent known to pass tailrace receivers but did not pass dams							
Number	21	56	7	6	12	0	7
Percent	2.5	10.1	1.8	0.3	10.0	0.0	5.8

[a] Recaptures of chinook salmon without or with non-functioning transmitters at the Lower Granite adult trap, and transportation of chinook salmon to upriver hatcheries accounts for low top-of-ladder receiver efficiency.

upstream from a hatchery that usually has a significant number of returning adults.

Tailrace receiver efficiency, the percentage of tagged chinook salmon known to have passed the tailrace receivers that were recorded there, ranged from 73.3% at Lower Granite Dam to 94.1% at Bonneville Dam (Table 6). Lower efficiency at Lower Granite and Ice Harbor tailrace sites was caused in part by a relatively high number of receiver outages during the 1996 migration (Table 4) and because we tried to cover those tailraces with antennas on only one side of the river. Top-of-ladder receiver efficiency, the percentage of tagged chinook salmon known to have passed top-of-ladder receivers that were recorded there, was higher than 86% at all dams except Lower Granite Dam (Table 6). At Lower Granite Dam, some chinook salmon with transmitters were taken from the ladder trap, the transmitters were removed, and they were transported to an upriver hatchery was the primary reason that fewer fish were recorded at the top of the ladder than were recorded at the tailrace receiver. Also at Lower Granite Dam, we had the opportunity to recapture tagged salmon and determine the percentage of fish that had regurgitated transmitters and that had non-functioning transmitters. When transported fish and those with transmitter problems were accounted for, top-of-ladder receiver efficiency at Lower Granite Dam was almost 100%. Similarly, we used upriver recapture records to verify passage of chinook salmon not recorded at other tailrace and top-of-ladder receivers. Because of uncertainty about timing of transmitter loss or failure, however, it was difficult to determine when a lack of records at a site for a fish was caused by receiver inefficiency or transmitter problems. All fish were treated as if they had functioning transmitters downstream from Lower Granite Dam and, therefore, reported receiver efficiency at all sites may be slightly lower than actual efficiency.

Median, first and third quartile passage dates, taken from the last record at the top of a ladder at each dam, were progressively later as spring and summer chinook salmon outfitted with transmitters moved upriver in 1996, with a slight exception at Ice Harbor Dam (Figure 12). Median first passage dates for all fish were 10 May at Bonneville Dam, 15 May at The Dalles, 17 May at John Day, 31 May at McNary, 28 May at Ice Harbor, 6 June at Lower Granite and 3 July at Priest Rapids. Median first passage dates for spring chinook salmon progressed upriver from 6 May at Bonneville Dam to 26 May at Priest Rapids and 3 June at Lower Granite, and for summer chinook salmon progressed from 20 June at Bonneville Dam to 5 July at Priest Rapids Dam and 4 July at Lower Granite Dam (Figure 12). Fifty percent of spring chinook salmon passed each dam within 13 days prior to and 15 days after the median passage date; 50% of summer chinook salmon passed within 10 days prior to and 5 days after the median date.

At Bonneville and The Dalles dams, passage date distributions were approximately the same as the distribution of tagging dates with a lag of several days for each project (Figure 13). At John Day and McNary dams, passage date distributions began to reflect a split between spring and summer chinook salmon runs that became more apparent on passage distributions for Ice Harbor and Priest Rapids dams (Figure 13). In 1996, most summer chinook salmon that passed McNary Dam were bound for Priest Rapids Dam and mid Columbia River tributaries, while a majority of spring chinook salmon were bound for the Snake River. Of 103 chinook salmon recorded at the tops of Ice Harbor Dam ladders, 82 (80%) were spring chinook salmon and 21 (20%) were summer chinook salmon. Of 111 chinook salmon recorded at the tops of Priest Rapids Dam ladders, 33 (30%) were spring chinook salmon and 78 (70%) were summer chinook salmon.

Chinook salmon with transmitters passed tailrace receivers throughout the day and night in 1996, with a tendency for most salmon to approach Bonneville and Lower Granite dams during daylight hours

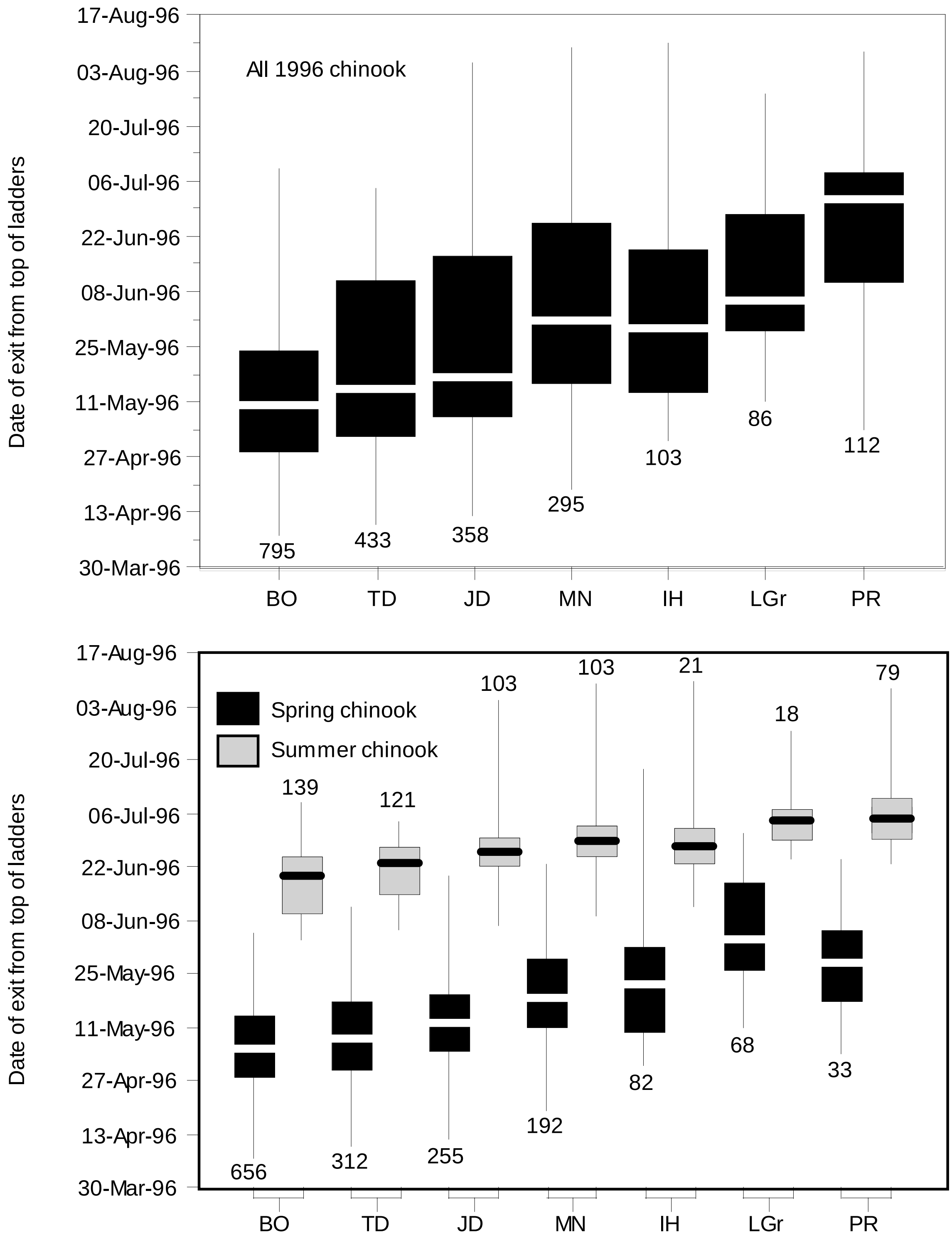


Figure 12. Median, first quartile, third quartile and range of passage dates for all chinook salmon with transmitters that passed Columbia and Snake River dams in 1996, and for spring and summer chinook salmon separately. Numbers of fish recorded at each dam adjacent to each range line.

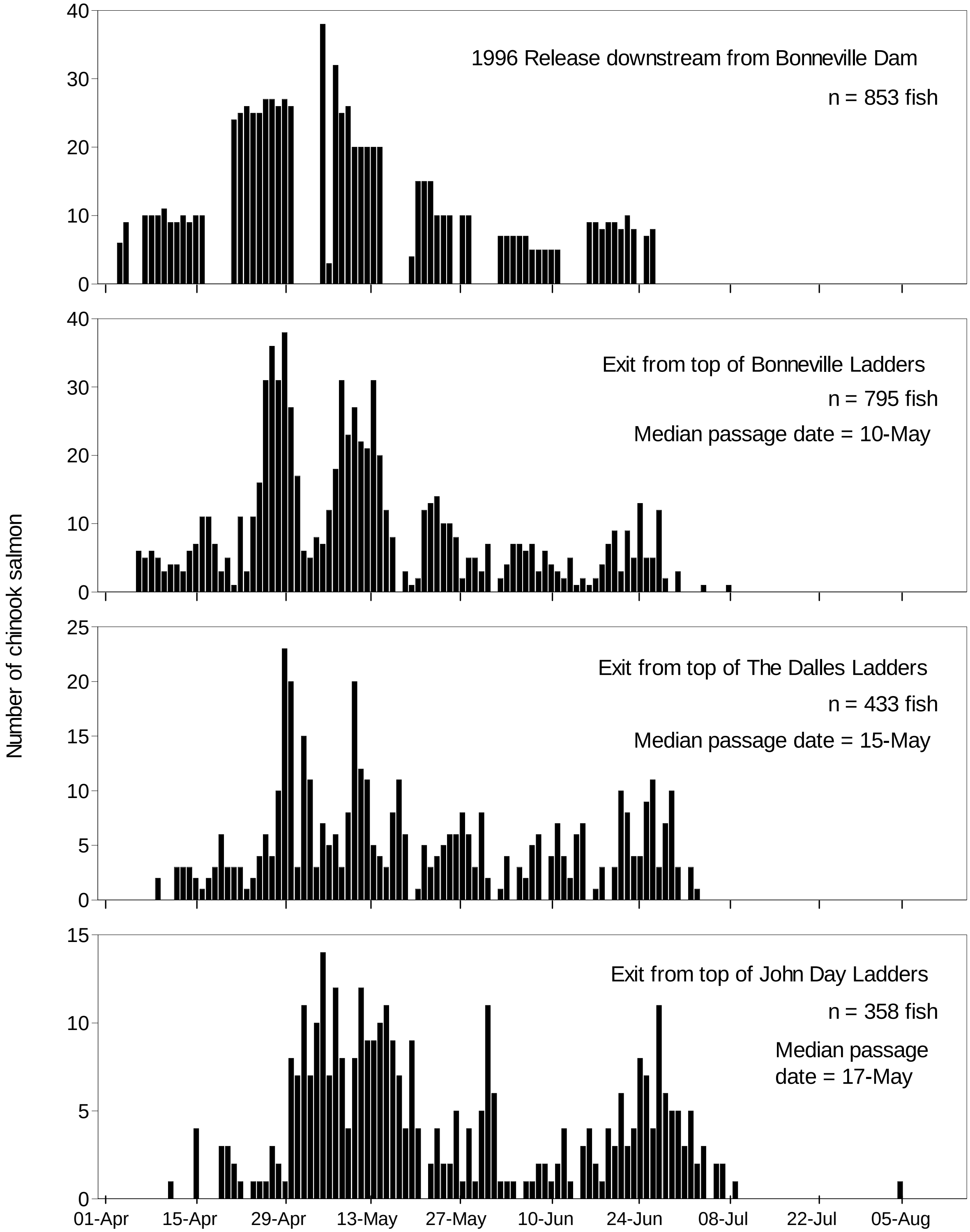


Figure 13. Frequency distributions for the date that chinook salmon were tagged at Bonneville and the date they first were recorded at the tops of ladders at Bonneville, The Dalles, John Day, McNary, Priest Rapids, Ice Harbor and Lower Granite dams in 1996.

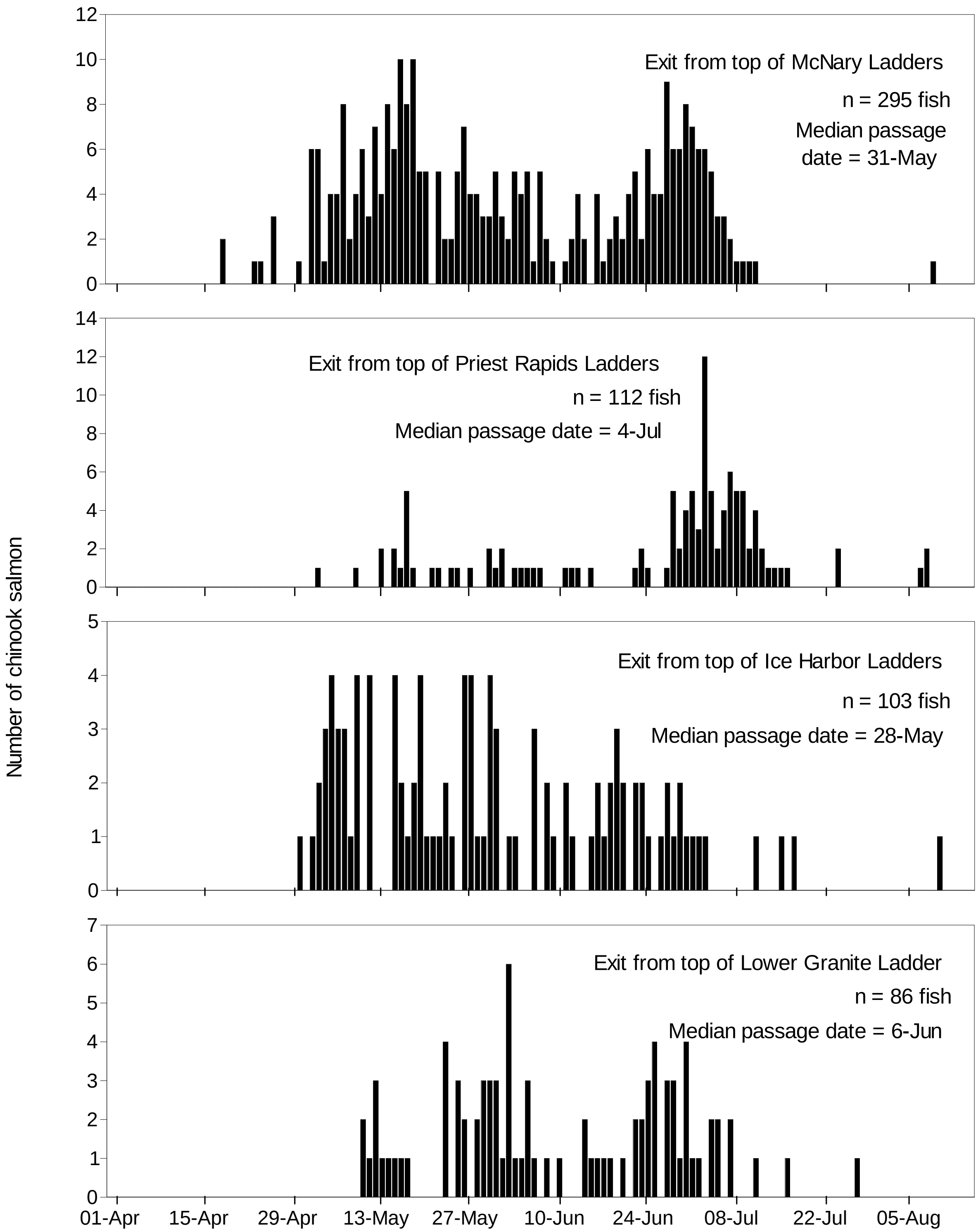


Figure 13. Continued.

(Figure 14). By comparison, chinook salmon passed top-of-ladder receivers almost exclusively during daylight hours, though a small number of fish that were in ladders during late afternoon and evening did pass dams after 2100 hours.

Median times for spring and summer chinook salmon to pass each of the dams studied in 1996 were less than 1.6 d per dam (Figure 15). Median passage times from the tailrace receiver to exit from the top of a ladder were 0.96 d at Bonneville Dam, 0.93 d at The Dalles, 1.26 d at John Day, 1.03 d at McNary, 0.75 d at Ice Harbor, 1.59 d at Lower Granite and 1.51 d at Priest Rapids dams (Table 7). Longer passage at Lower Granite Dam was caused by operation of the adult trap that delayed all fish diverted into the trap. Mean passage times were longer than median times at all dams because a few fish took several days to pass dams and all distributions were skewed to the right. We have presented both mean and median values, but believe medians more accurately portray the time most fish take to pass over a dam or through a reservoir.

At Bonneville, The Dalles and Ice Harbor dams, less than 10% of chinook salmon with transmitters took more than 5 days to pass the dams. Eleven percent to 15% took more than five days to pass John Day, McNary, Lower Granite and Priest Rapids dams. At all dams, less than 6% took more than 10 days to pass, but individual chinook salmon took up to 42 d to pass an individual dam (Table 7). At McNary, Lower Granite, and Priest Rapids dams, 4.8% to 5.5% of the chinook salmon took more than 10 days to pass over the dams.

Effects of Environmental Conditions on Chinook Salmon Passage at Dams

In general, daily spill volumes at Columbia and Snake River dams in 1996 fluctuated with total flow at each dam (Figure 16). Dissolved gas levels were also highly correlated with total flow. Annual high spill and flow volumes at lower Columbia River dams occurred between mid-May and late June, with peak flows near 475 kcfs on 11 June. Ice Harbor, Lower Granite and Priest Rapids dams also had annual peak flow and spill between mid-May and late June, and all dams had shorter, lower-volume peaks in mid-April. A block of highly turbid water passed through the lower Columbia River in early May, approximately coincident with a period of intermediate flow and spill volumes between peak flows in April and late May. Secchi disk visibility dropped to annual low levels of < 0.5 m at each dam during this time.

In 1996, flows, spill, and turbidity were relatively high, but neither spill nor flow appeared to affect passage of chinook salmon at the dams (Figure 17). At Bonneville Dam, peak counts of spring chinook salmon occurred when flow and spill decreased temporarily in mid May, but at McNary and Ice Harbor dams, peak counts occurred a few days later when flow and spill had increased again. Correlations of time to pass a dam versus flow and spill were low (r^2 less than 0.07) despite a large range of flows and spills during the spring season (Figures 18 and 19). The spill values presented in Figures 17 and 19 were average daily spill volumes. Because most salmon pass the dams during the daytime, we also looked at daytime spill versus time to pass at Bonneville Dam, but spill volumes and r^2 values were similar to the prior analyses.

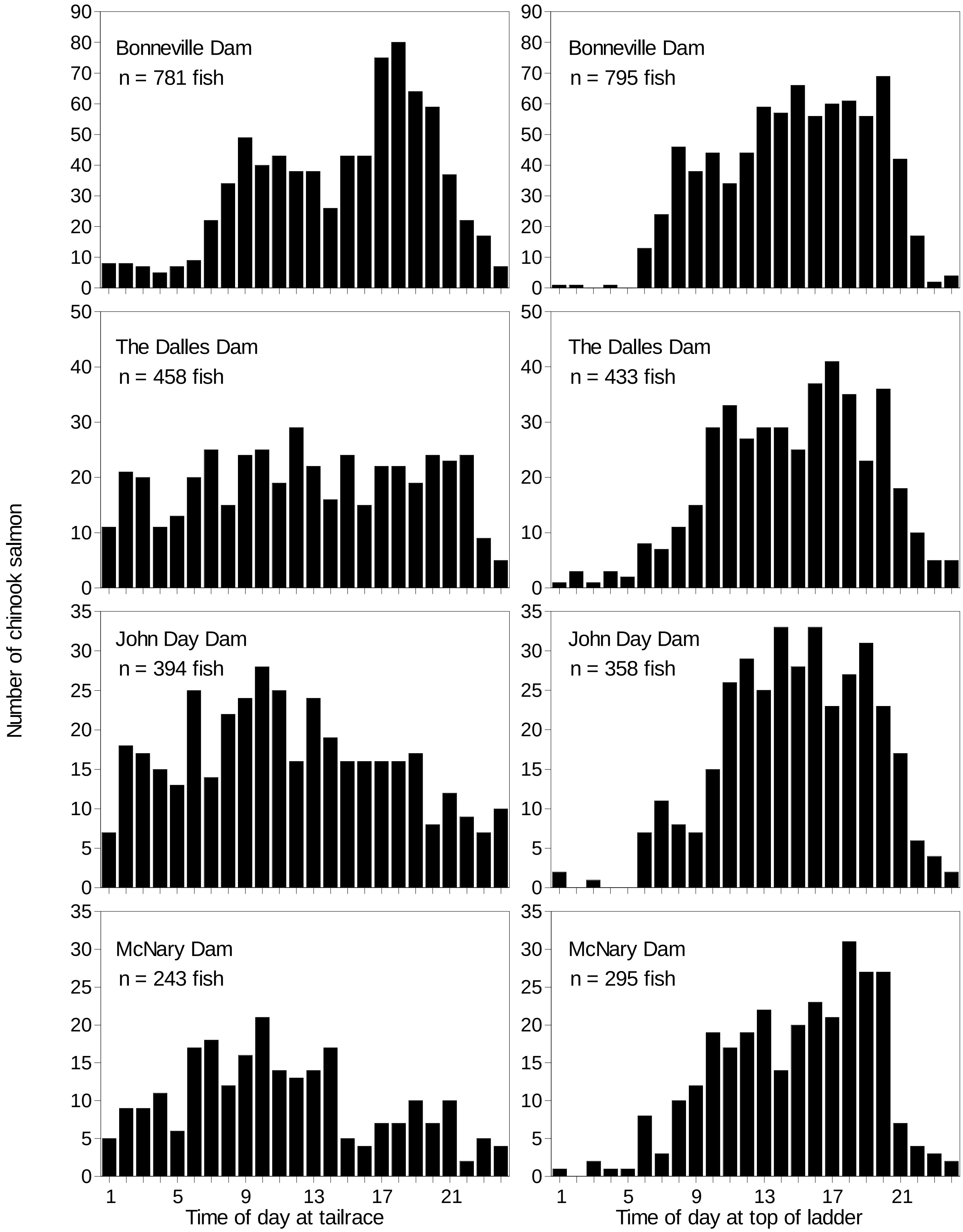


Figure 14. Frequency distribution of time of day that chinook salmon with transmitters were first recorded at tailrace receivers and last recorded at top-of-ladder receivers at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Granite, and Priest Rapids dams in 1996.

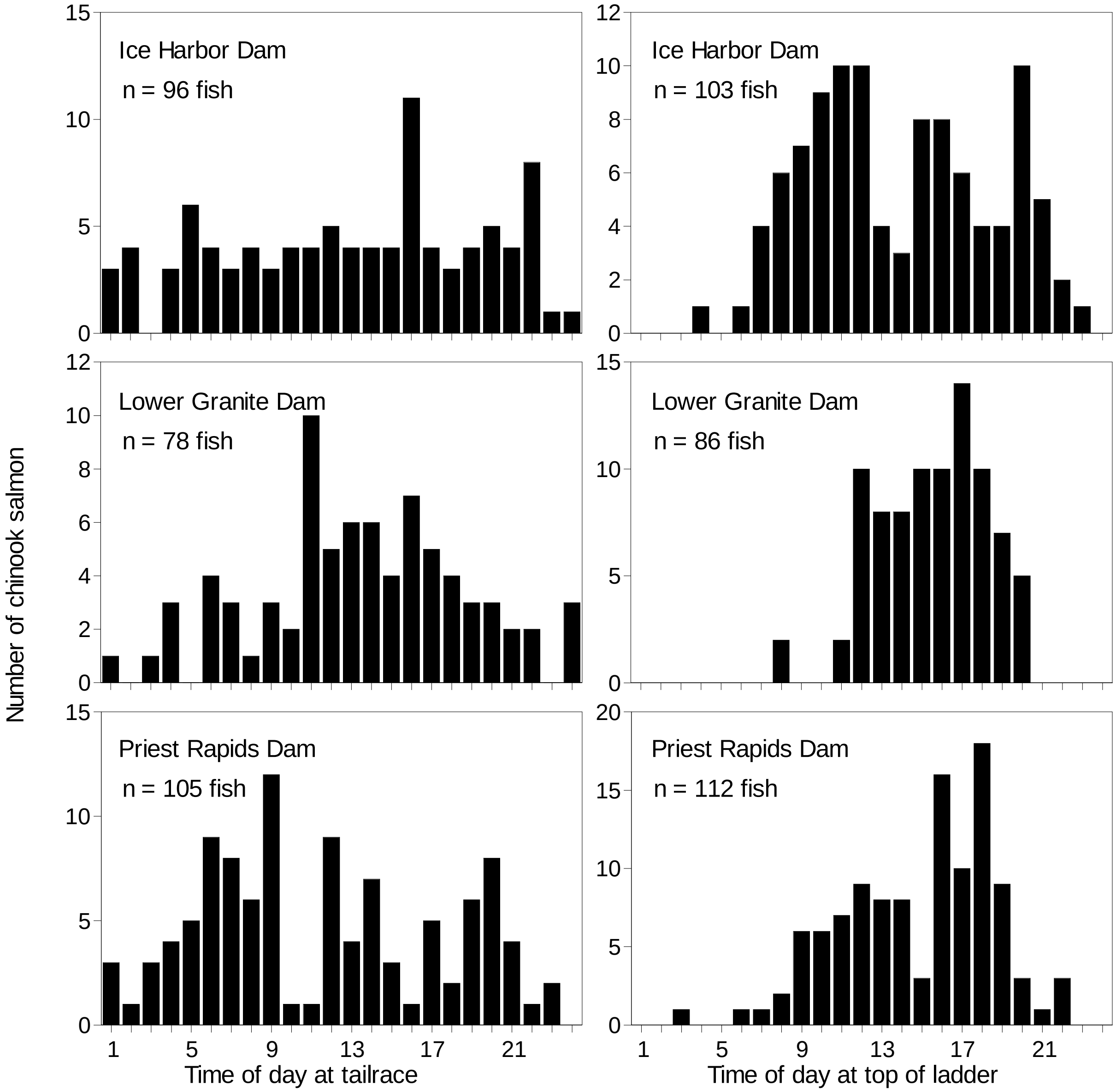


Figure 14. Continued.

A temporary decrease in counts at Bonneville Dam during the first few days in May , normally the peak of the spring chinook salmon run, was probably caused by high turbidity when Secchi disk visibility was less than 0.5 m (Figure 20). A rain storm along the north side of the Columbia River caused washouts and flooding in north side tributaries. In the Snake River, peak turbidity occurred about 20 May at

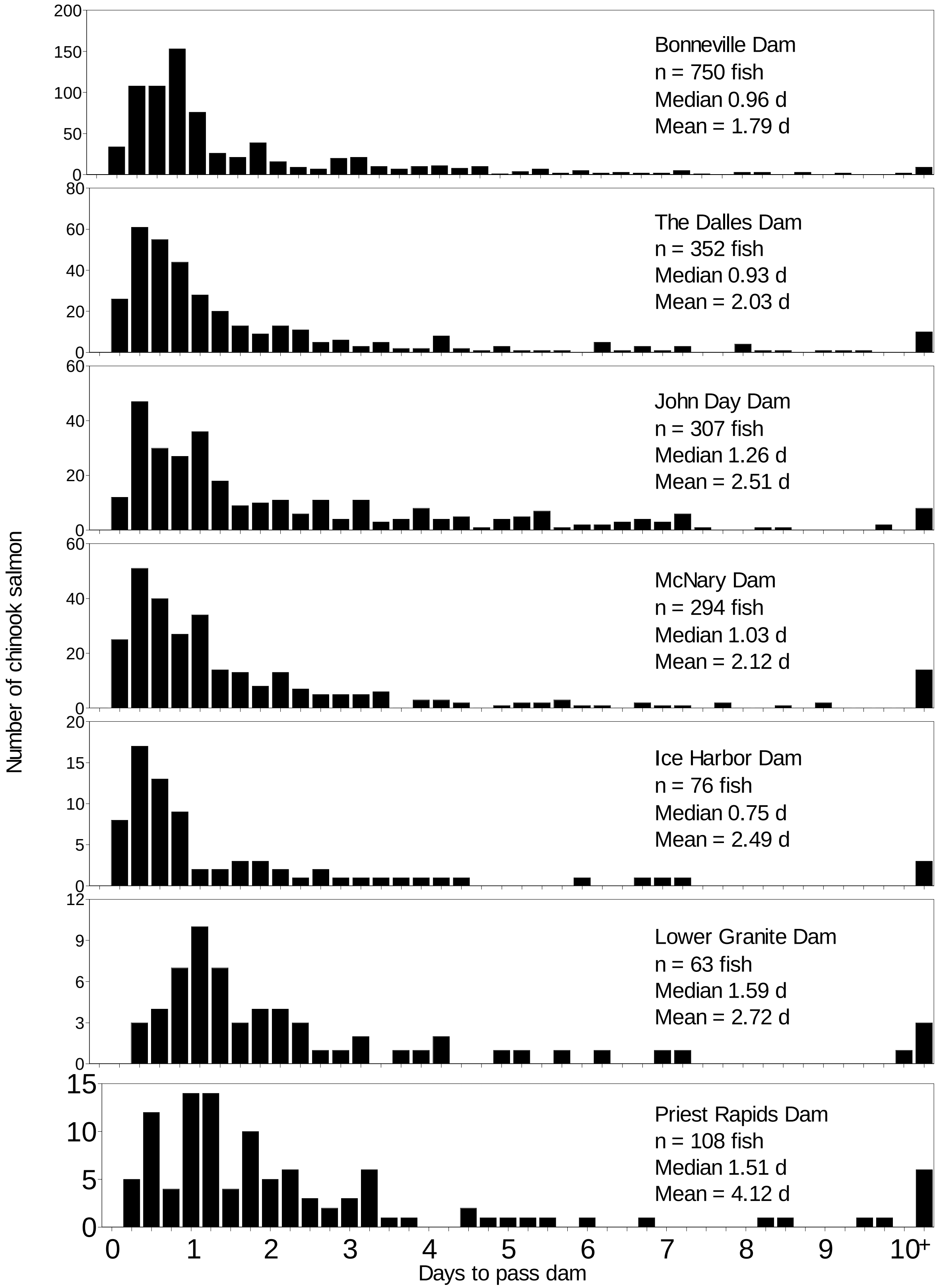


Figure 15. Number of chinook salmon and time in days to pass from tailrace receivers to top-of-ladder receivers at dams monitored in 1996.

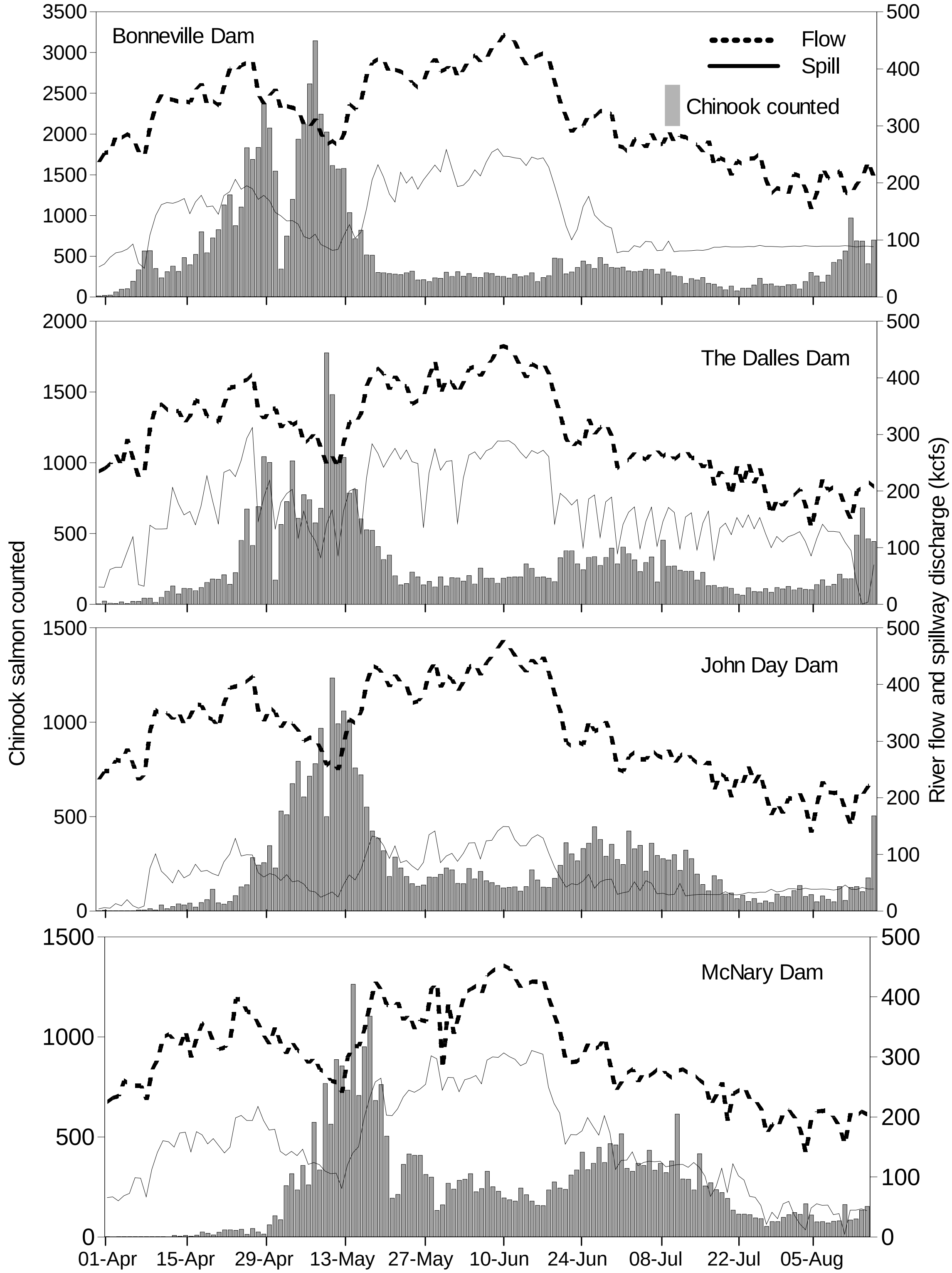


Figure 16. Mean total flow and spillway discharge (kcfs) at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Granite and Priest Rapids dams during the spring and summer chinook salmon migration, and the number of chinook salmon counted passing each dam.

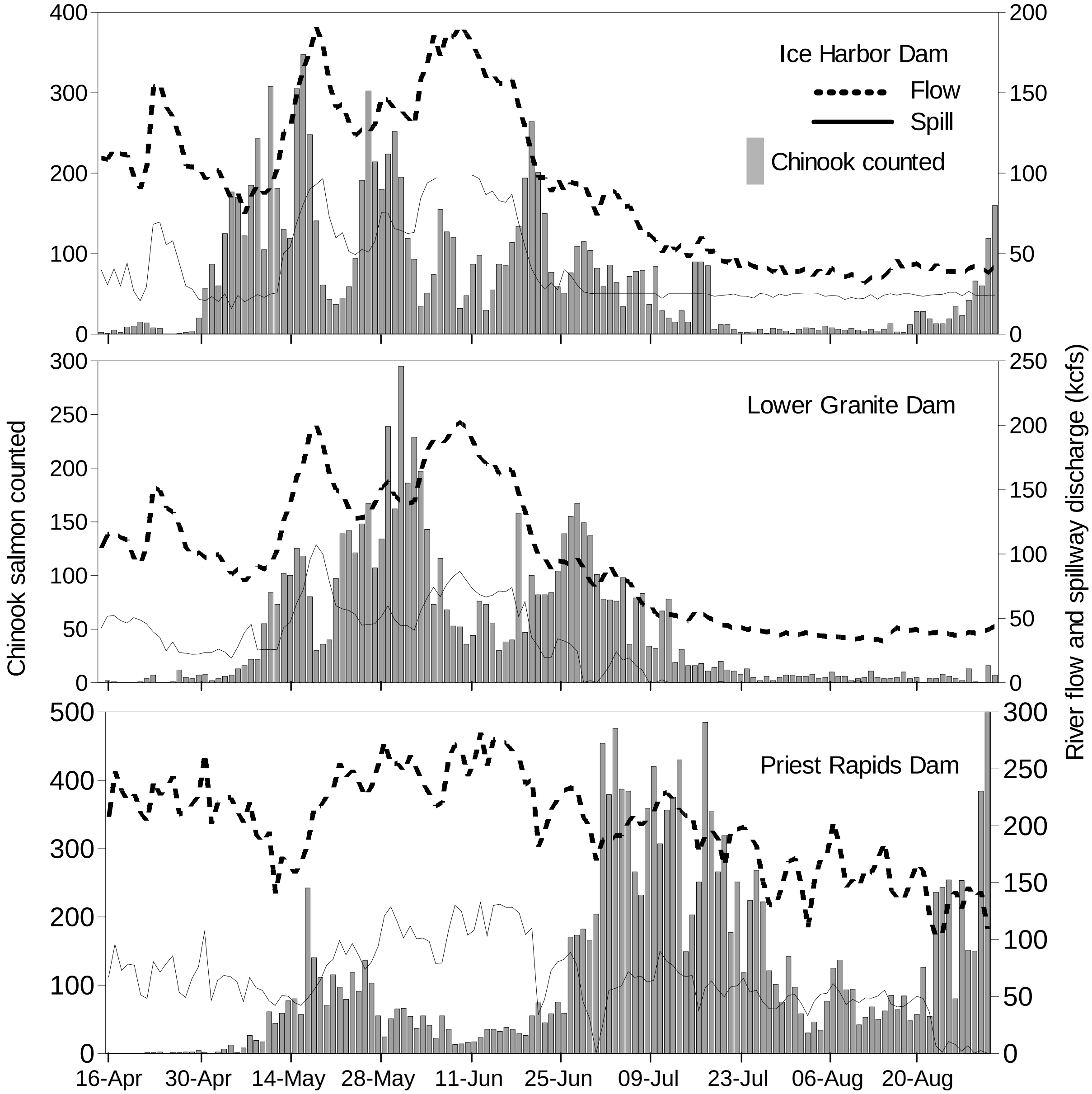


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Figure 16. Continued.

Lower Granite Dam and a few days later at Ice Harbor Dam, and decreased counts of salmon occurred when we would not have expected nadirs.

Disruptions in the pattern of passage of spring chinook salmon with transmitters at Bonneville Dam were similar to interruptions in total counts of fish at the

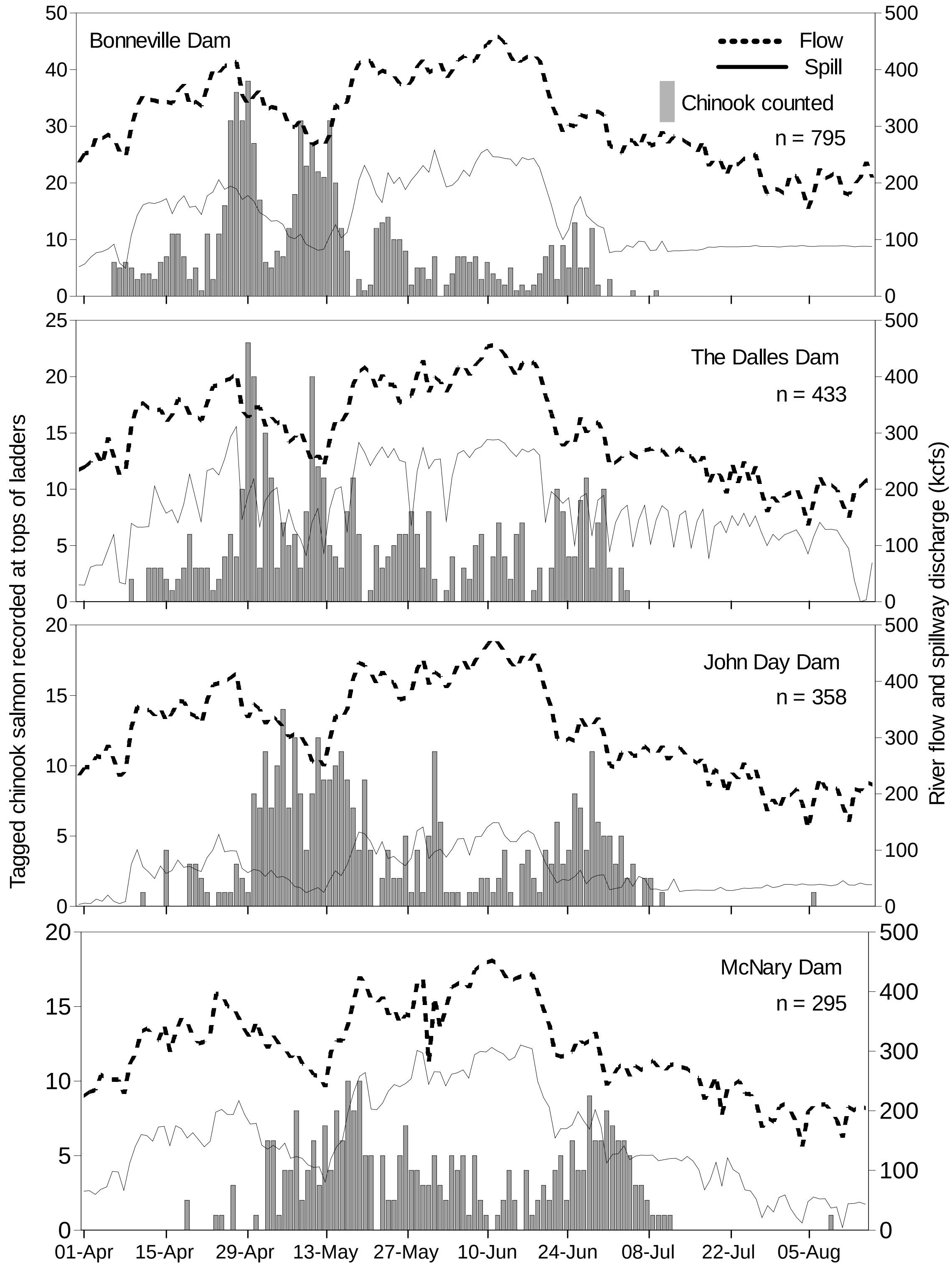

Figure 17. Daily mean total flow and spillway discharge (kcfs) at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Granite and Priest Rapids dams during the 1996 chinook salmon migration, with number of radio-tagged chinook salmon that passed dams.

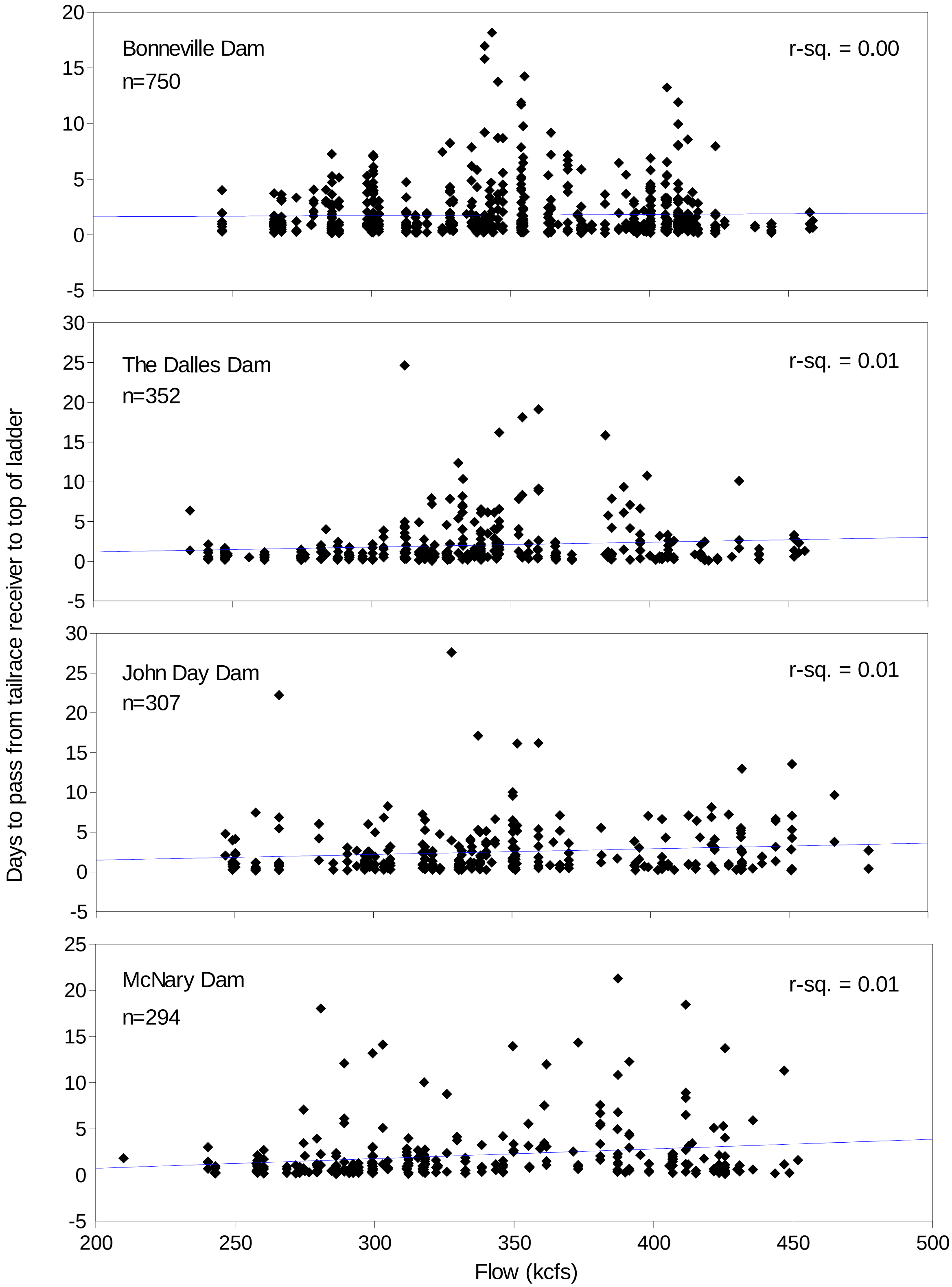

Figure 18. Relationship between total flow at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Granite and Priest Rapids dams and time for chinook salmon to pass from tailrace receivers to top-of-ladder receivers in 1996.

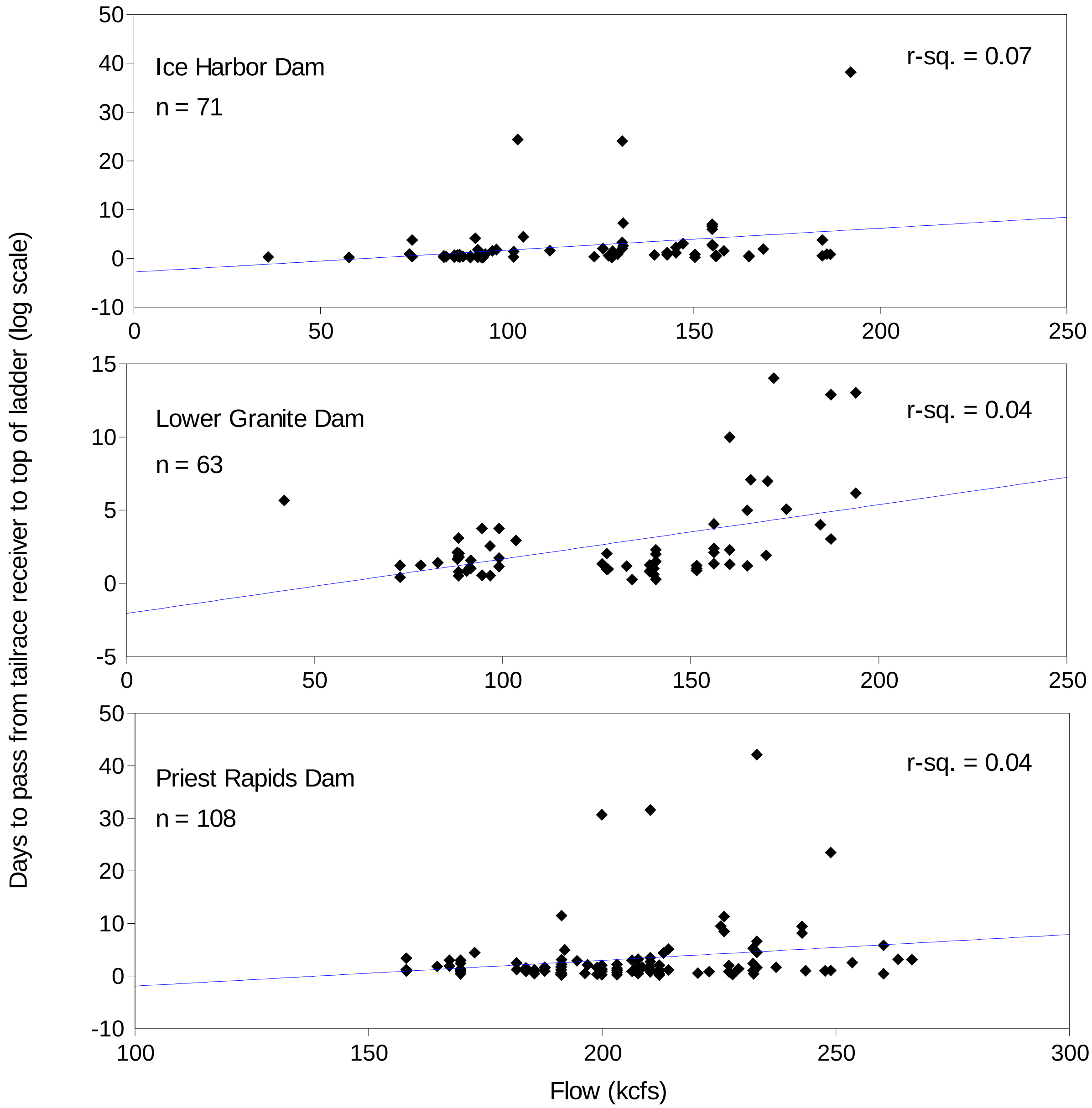

Figure 18. Continued.

dam, but some of the disruption was caused by the periodic cessation of tagging for 4 d during each two week period (Figure 5). One of the periods with no tagging was in early May and happened to coincide with the period of high turbidity. Secchi disk visibility at the time that chinook salmon passed tailrace receivers and passage times past individual dams was not strongly correlated with passage time in 1996. There was a slight tendency for passage times to increase with increased turbidity, but r^2 values were 0.06 or lower at all dams except Lower Granite Dam, where $r^2 = 0.12$ (Figure 21). (At Ice Harbor, Lower Granite and Priest Rapids dams, regressions of turbidity and passage time for chinook salmon were substantially influenced by a few outlying data points,

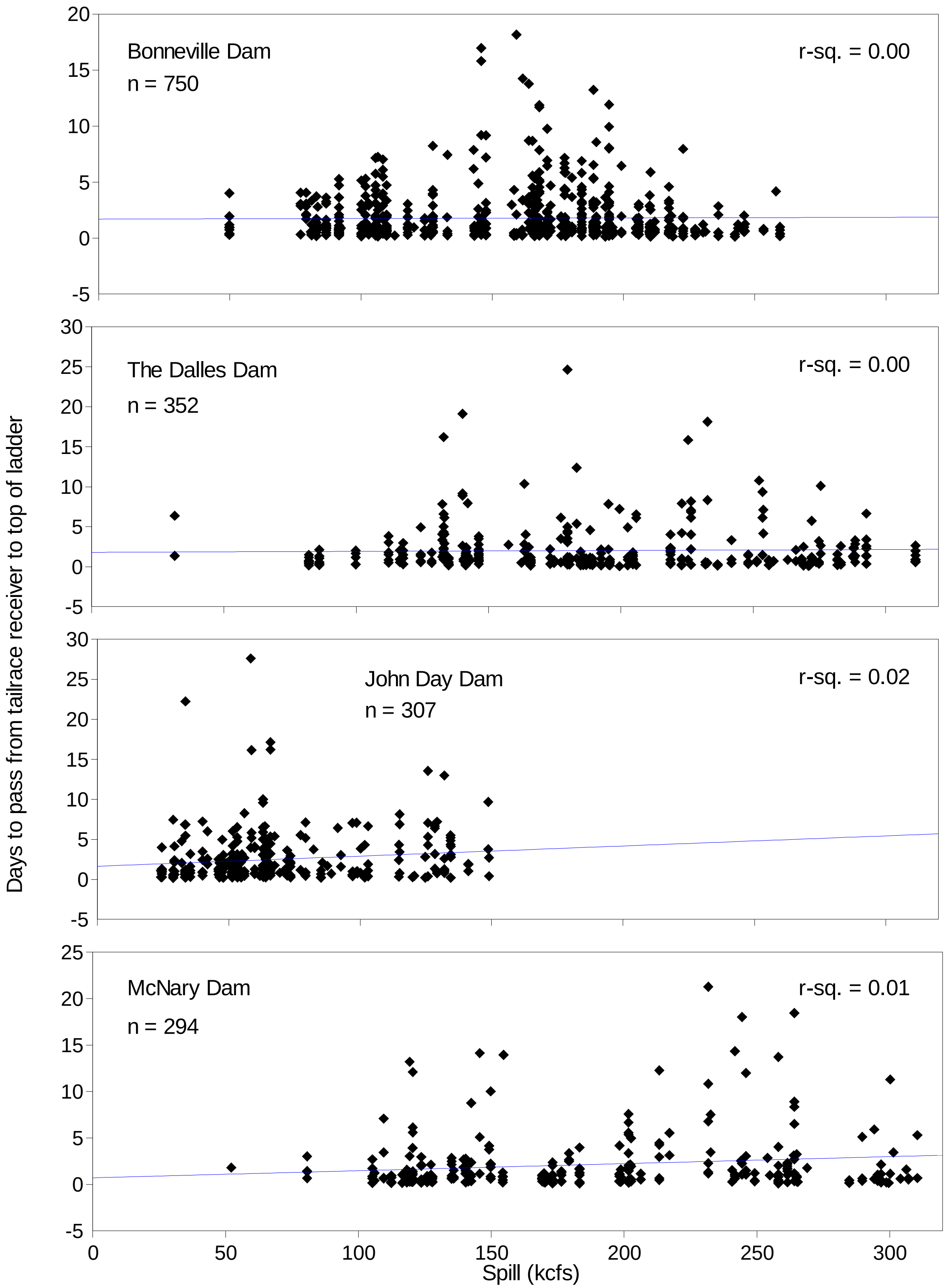

Figure 19. Relationship between spill at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Granite and Priest Rapids dams and time for chinook salmon to pass from tailrace receivers to top-of-ladder receivers in 1996.

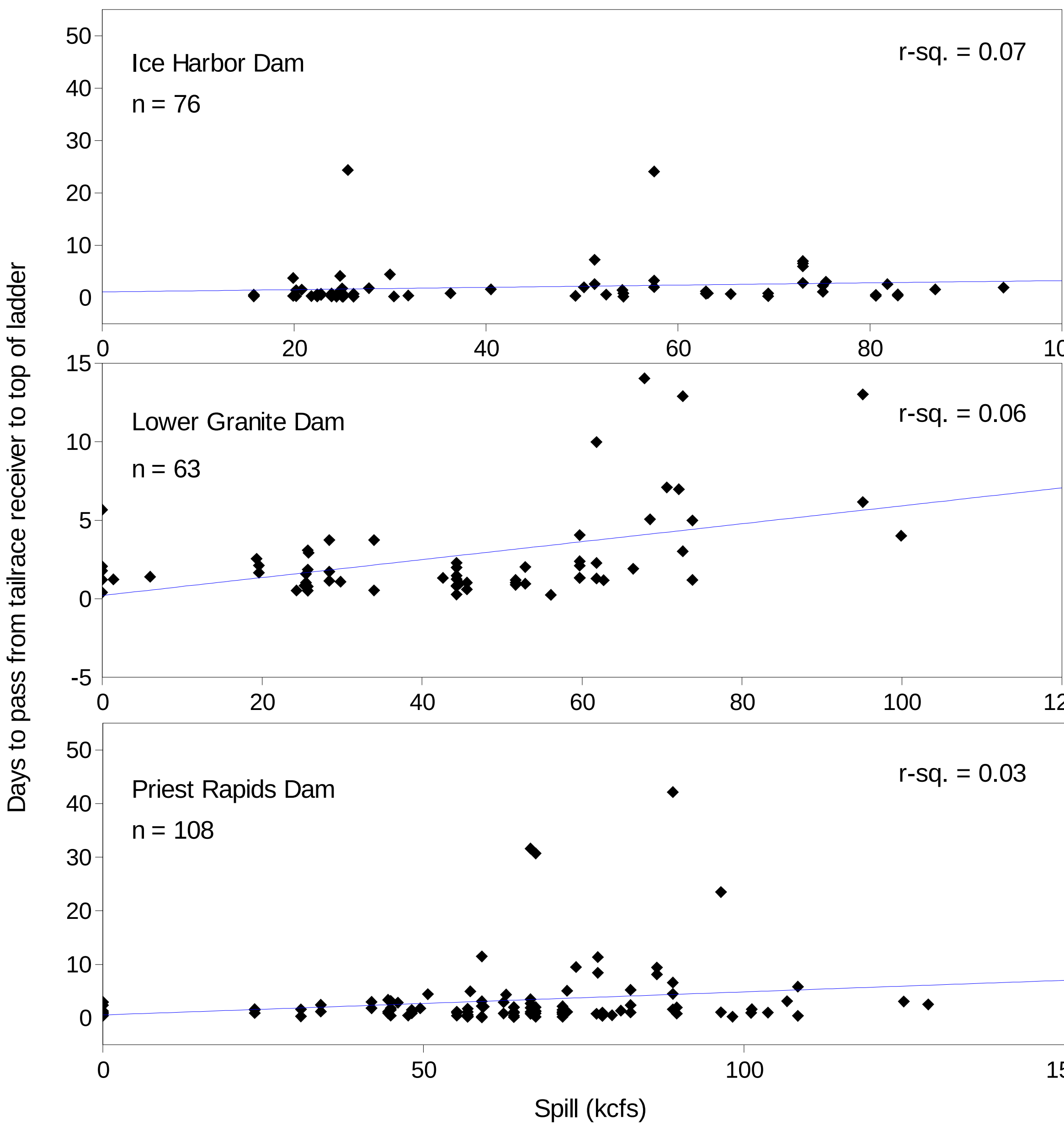

Figure 19. Continued.

i.e. fish that took 10 or more days to pass a dam.)

Although linear relations between flow, spill, and passage times had low correlations, we found that median passage times were higher for fish that passed some dams during periods of high flow and spill. At The Dalles and McNary dams, median passage times for tagged chinook salmon that passed when flows were more than 300 kcfs were 1.6 times longer than for fish that passed when flows were less than 300 kcfs. Similarly, median passage time for 132 chinook salmon that passed John Day Dam when flows were higher than 350 kcfs was 1.6 times longer than for 175 fish that passed

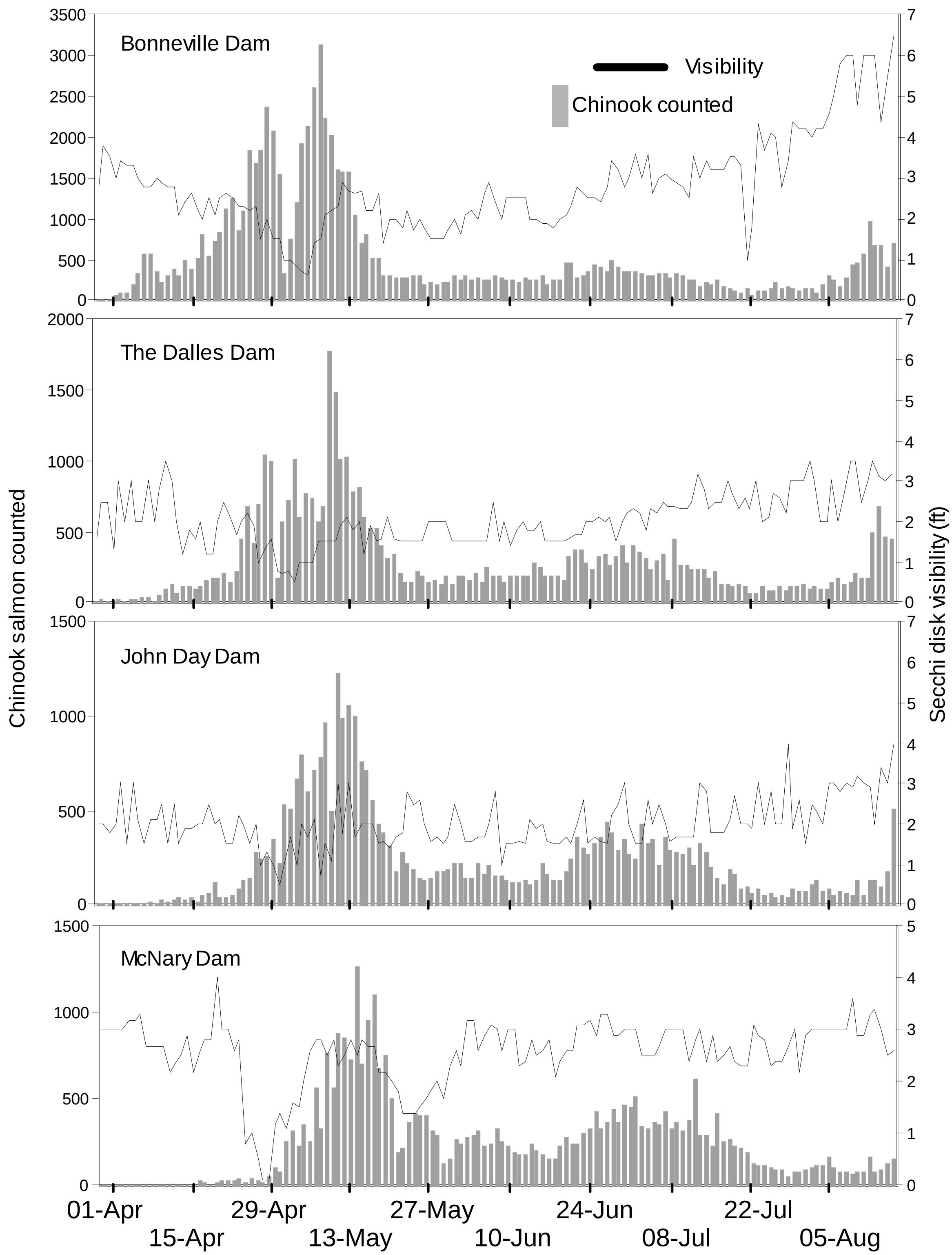

Figure 20. Daily mean Secchi disk visibility (ft) at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Granite, and Priest Rapids dams during the 1996 spring and summer chinook salmon migration, with number of chinook salmon counted passing dams.

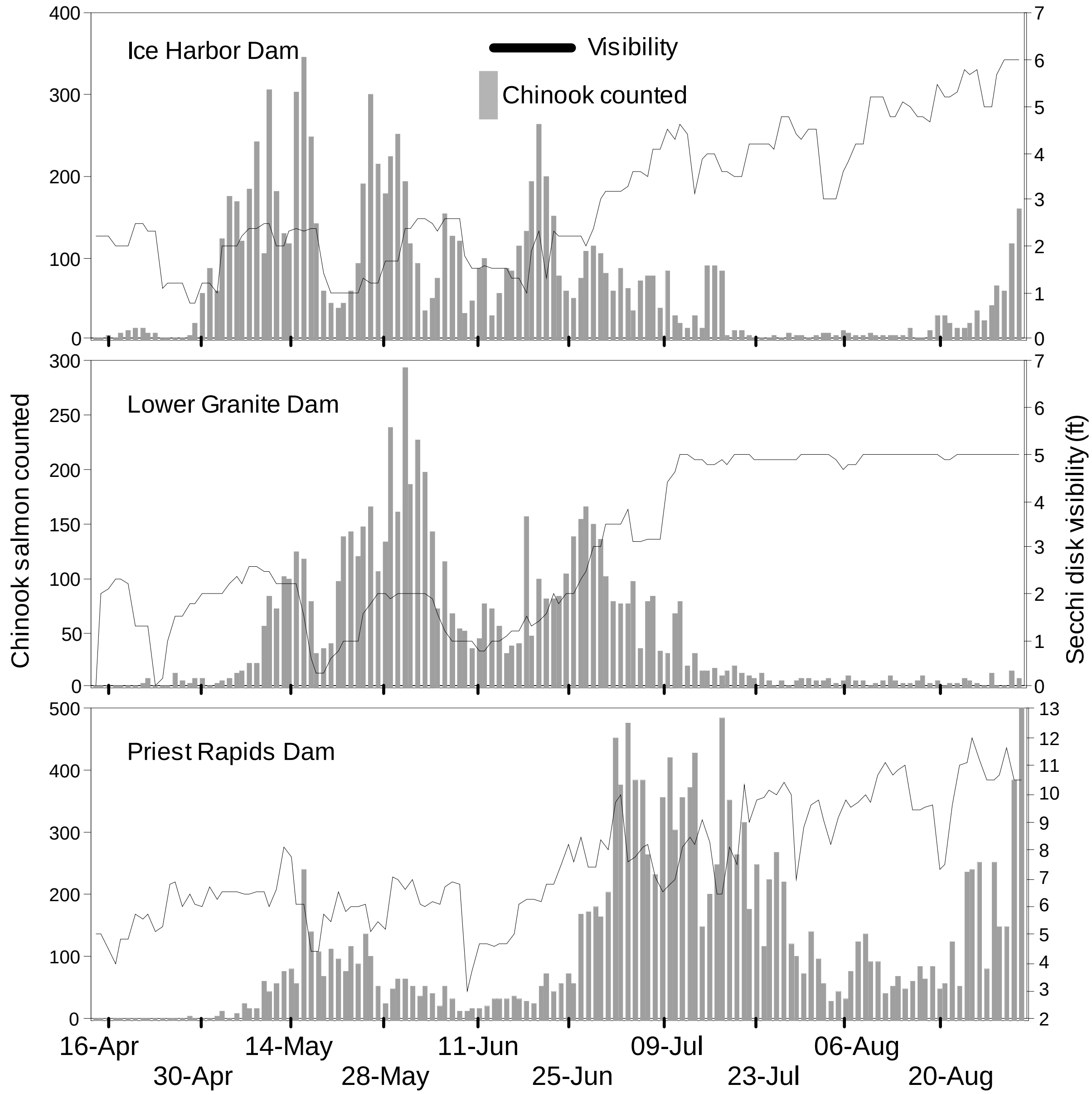

Figure 20. Continued.

when flows were less than 350 kcfs. At Ice Harbor Dam median passage times were 0.49 d for 35 fish that passed when flows were less than 100 kcfs and 1.46 d for 41 fish that passed when flows exceeded 100 kcfs.

Higher spill volumes appeared to have some effect on median passage times at Ice Harbor, Lower Granite, McNary and John Day dams. At Ice Harbor Dam, median passage for 30 chinook salmon that passed when spills exceeded 50 kcfs was 1.51 d, three times longer than for 41 fish that passed when spills were less than 50 kcfs. At Lower Granite Dam, median passage for 27 fish that passed when spill exceeded 50 kcfs was 2.29 d, 1.8 times longer than for 36 fish that passed when spills were less than 50 kcfs.

Table 7. Mean, median and range of days for spring and summer chinook salmon to pass each dam from tailrace receiver sites to tops of ladders, with standard deviations and percentages of fish that took more than 5 and 10 days to pass dams monitored in 1996.

	Bonneville	The Dalles	John Day	McNary	Ice Harbor	Lower Granite	Priest Rapids
Number of fish							
	750	352	307	294	76	63	108
Mean days to pass dam							
	1.79	2.03	2.51	2.12	2.49	2.72	4.12
Median days to pass dam							
	0.96	0.93	1.26	1.03	0.75	1.59	1.51
Range of days to pass dam							
Min	0.15	0.07	0.20	0.11	0.18	0.26	0.14
Max	18.2	24.7	27.6	21.3	38.2	14.0	42.2
Standard deviations							
	2.21	3.05	3.22	3.18	5.73	3.01	6.20
Percentage of fish that took more than 5 days to pass dam							
	7.3	9.9	15.0	10.9	9.2	14.3	12.9
Percentage of fish that took more than 10 days to pass dam							
	1.2	2.8	2.6	4.8	3.9	4.8	5.5

Median passage time for 251 chinook salmon with transmitters at John Day Dam was 1.17 d at spills less than 100 kcfs and 2.66 d at spills higher than 100 kcfs. At McNary Dam, median passage time was 0.89 d for 181 chinook salmon that passed when spills were less than 200 kcfs and 1.43 d for 113 fish that passed when spills exceeded 200 kcfs.

When we used stepwise multiple regression models to evaluate the effect of environmental conditions on passage time from the tailrace to the top-of-ladder sites at Bonneville Dam, we found that environmental conditions at the time chinook salmon arrived in the tailrace accounted for a small proportion of the variability in passage times. We included date of first tailrace record as well as total flow, spill, Secchi disk depth, and dissolved gas level at the first record date in the first model, and used a $P < 0.15$ criteria for inclusion in the regression model. Tailrace date was the first variable selected by the model, with an r^2 value of 0.07 (Table 8). Secchi disk depth, spill, and dissolved gas were added to the model, but the r^2 value only improved to 0.09. In a second model, we did not include first tailrace date, but retained dissolved gas, flow, and Secchi depth in the model, but the r^2 value was less than 0.02 (Table 8). Removal of individual fish with passage times longer than 5 d led to minor improvements in model r^2 values.

In similar multiple regression analyses for passage at The Dalles Dam, first tailrace date had an r^2 value of 0.10; the

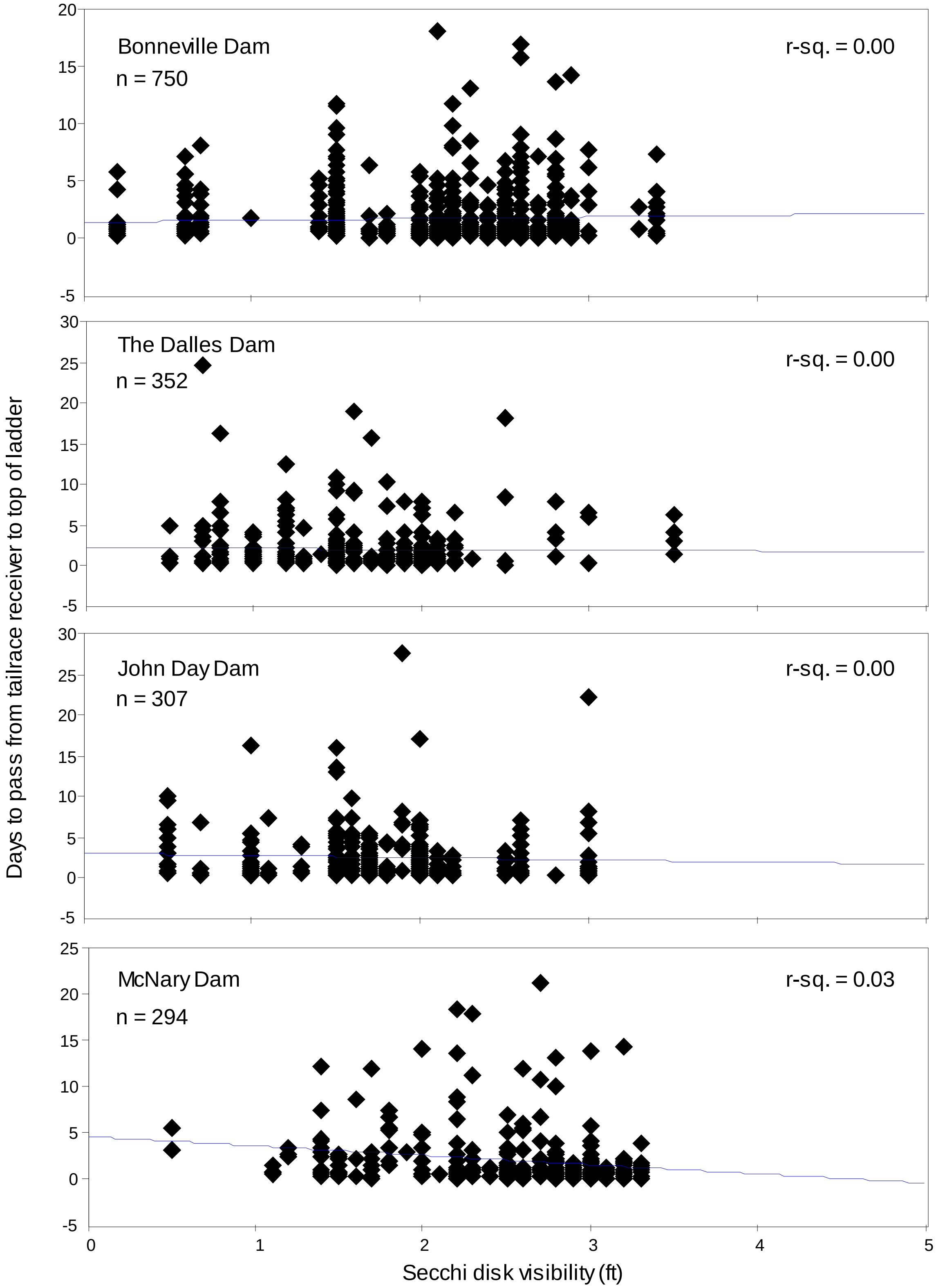

Figure 21. Relationship between Secchi disk visibility at Bonneville, The Dalles, John Day, McNary, Ice Harbor, Lower Granite, and Priest Rapids dams and time for chinook salmon to pass from tailrace receivers to top-of-ladder receivers in 1996.

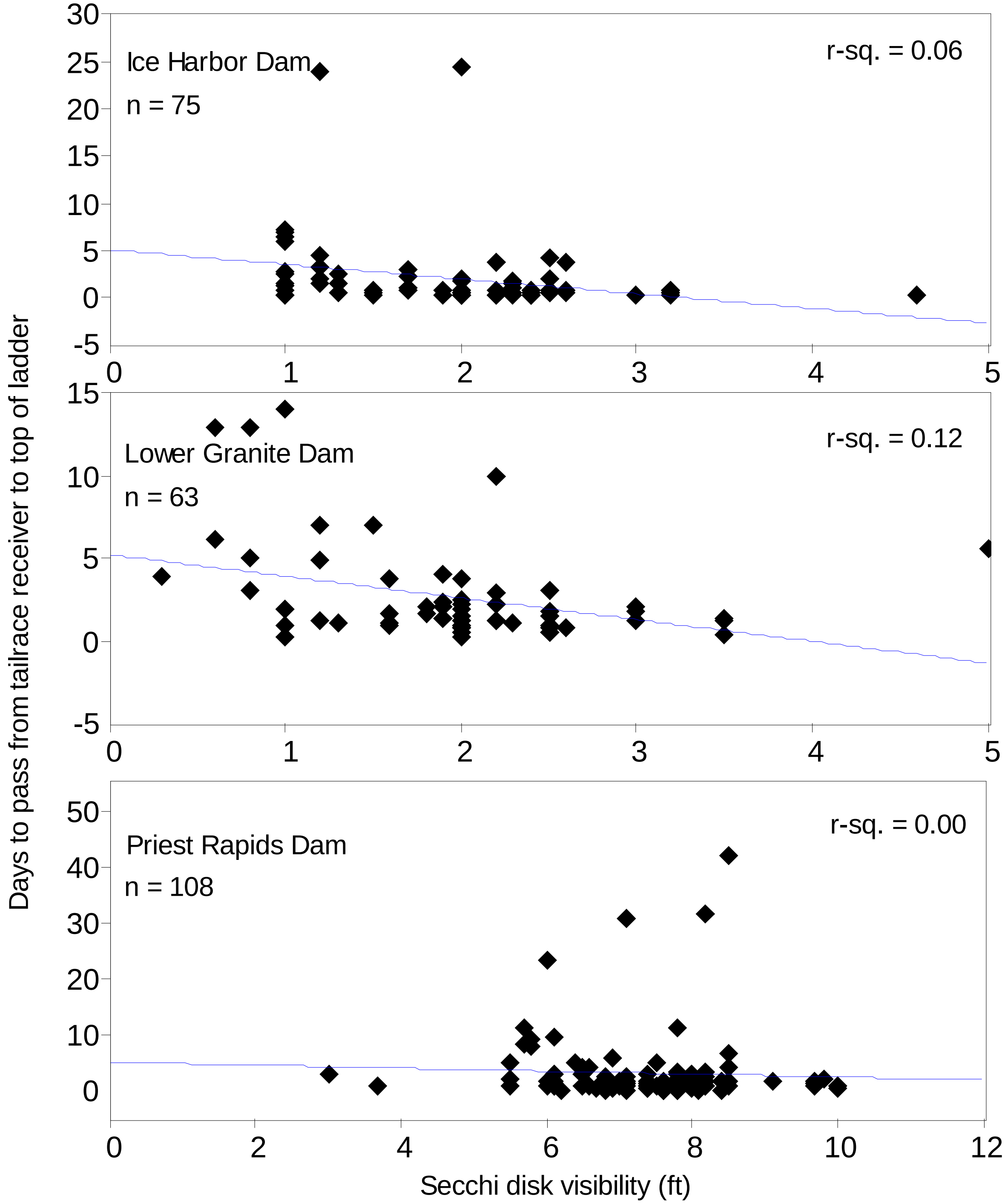

Figure 21. Continued.

Table 8. Stepwise multiple regression model outputs for the first passage of chinook salmon at Bonneville Dam in 1996, including models run, variables retained, and standard procedure outputs.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Model 1, Flow, spill, Secchi depth, dissolved gas, date of first tailrace record						
	a. First tailrace date		0.0736	0.0736	59.45	0.0001
	b. Secchi depth		0.0777	0.0041	3.31	0.0692
	c. Spill		0.0817	0.0040	3.28	0.0705
	d. Dissolved gas		0.0890	0.0072	5.90	0.0153
Model 2, Flow, spill, Secchi depth, dissolved gas						
	Gas, Flow, Secchi depth retained, but r^2 value was less than 0.02 for model					

addition of flow improved the r^2 value to 0.12. When tailrace date was removed, flow and dissolved gas were retained by the model, but the r^2 value was less than 0.04. In analyses for passage at John Day Dam, only dissolved gas level was retained in the model, with an r^2 value of 0.03. Limiting the analyses to fish that passed John Day Dam in less than 5 d did not improve model r^2, but spill was the only significant variable selected, in place of dissolved gas. In analyses for passage at McNary Dam, first tailrace date and then spill were retained in the model, for an overall r^2 value of 0.09. When we removed tailrace date from the model, Secchi disk depth and flow were selected, with a model r^2 value of 0.05. Removal of all fish that passed in more than 5 d improved fit for both models at McNary Dam slightly.

In multiple regression analyses for passage at Ice Harbor Dam, flow was the only variable retained in the model, with r^2 value of 0.07. Tailrace date was not selected, and removal of flow from the model resulted in the selection of spill, with very similar model fit. For Lower Granite Dam, only Secchi disk depth, with r^2 value of 0.12, was retained in the model.

Passage through Lower Columbia River Reservoirs

Spring and summer chinook salmon with transmitters migrated relatively quickly through lower Columbia River reservoirs in 1996. Median passage times from top-of-ladder receivers to tailrace receivers at the next upriver dam were 1.63 d through the Bonneville pool, 0.84 d through The Dalles pool, 1.97 d through the John Day pool and 1.20 d through the McNary pool to the Ice Harbor tailrace (Figure 22). Because some fish took several days to pass through a pool, mean values were somewhat higher than medians. Migration rates for individual fish ranged from less than 5 km/day to more than 90 km/day through the pools. Median rates were 43.2, 45.0, 61.5 and 56.0 km/day through the Bonneville, The Dalles, John Day and McNary pools.

Median passage times through lower Columbia River reservoirs were significantly shorter for summer chinook salmon than for spring chinook salmon (Table 9). Ninety-nine summer chinook salmon passed through the Bonneville pool in a median of 1.28 d, compared to a median of 1.78 d for 349 spring chinook salmon. Median passage through The Dalles pool was 0.72 d for 88 summer chinook salmon and 0.90 d for 217 spring chinook salmon. Median passage time through the John Day pool was 1.96 d for 99 summer chinook salmon and 1.97 d for 192 spring chinook salmon. Seventeen summer chinook salmon passed the McNary pool to the Ice Harbor tailrace in a median of 1.06 d and 79 spring chinook salmon passed the McNary pool with a median of 1.23 d (Table 9). Median passage times were significantly ($P < 0.005$) lower for summer chinook salmon than for spring chinook salmon through the Bonneville, The Dalles, and McNary pools, but not through the John Day pool. Mean passage times and migration rates for spring and summer chinook salmon differed significantly ($P < 0.005$) through the Bonneville and The Dalles pools, but not through the John Day or McNary pools.

Passage Past Multiple Dams

Of the 838 salmon that retained transmitters after release, 96.5% were known to have passed over Bonneville Dam, 59.3% passed The Dalles, 45.0% passed John Day, 35.9% passed McNary, 14.3% passed Ice Harbor, 13.6% passed Lower Granite, and 13.5% passed Priest Rapids dams. We calculated median passage times past multiple dams from the Bonneville tailrace site to the tops of ladders at McNary, Ice Harbor, Lower Granite and Priest Rapids dams for salmon with transmitters that were recorded at top-of-ladder sites at those dams and at one of the tailrace receivers downstream from Bonneville Dam.

Passage times for 269 chinook salmon from the Bonneville Dam tailrace to the top of a McNary ladder ranged from 4.6 to 43.5 d with a median time of 11.9 d (Figure 23). Of these, 185 were spring chinook salmon, with a median passage time of 13.8 d and 84 were summer chinook salmon with a median passage time of 9.6 d (Table 10).

Passage times for 97 chinook salmon from the Bonneville Dam tailrace to the top of an Ice Harbor ladder ranged from 7.0 to 55.8 d with a median time of 16.8 d (Figure 23). Of the 97, 81 were spring chinook salmon, with a median passage time of 17.6 d and 16 were summer chinook salmon with a median passage time of 12.1 d (Table 10).

Passage times for 80 chinook salmon from the Bonneville Dam tailrace to the top of the Lower Granite ladder ranged from 10.8 to 64.0 d with a median of 27.2 d (Figure 23). Of these, 66 spring chinook salmon had a median passage time of 28.4 d and 14 summer chinook salmon had median passage time of 19.2 d (Table 10).

Passage times for 101 chinook salmon from the Bonneville Dam tailrace to the top of ladders at Priest Rapids Dam ranged from 8.7 to 63.9 d, with a median passage time of 16.7 d (Figure 23). Of these, 32 spring chinook salmon had a median passage time of 21.0 d, and 69 summer chinook salmon had a median passage time of 14.2 d (Table 10).

Passage time distributions were right-skewed for each river segment, and both mean and median summer chinook salmon passage times were significantly ($P < 0.005$) shorter than spring chinook salmon times for fish that passed McNary, Lower Granite and Priest Rapids dams. Median passage times were also significantly lower ($P < 0.05$) for summer chinook salmon from the Bonneville tailrace to the top of Ice Harbor Dam.

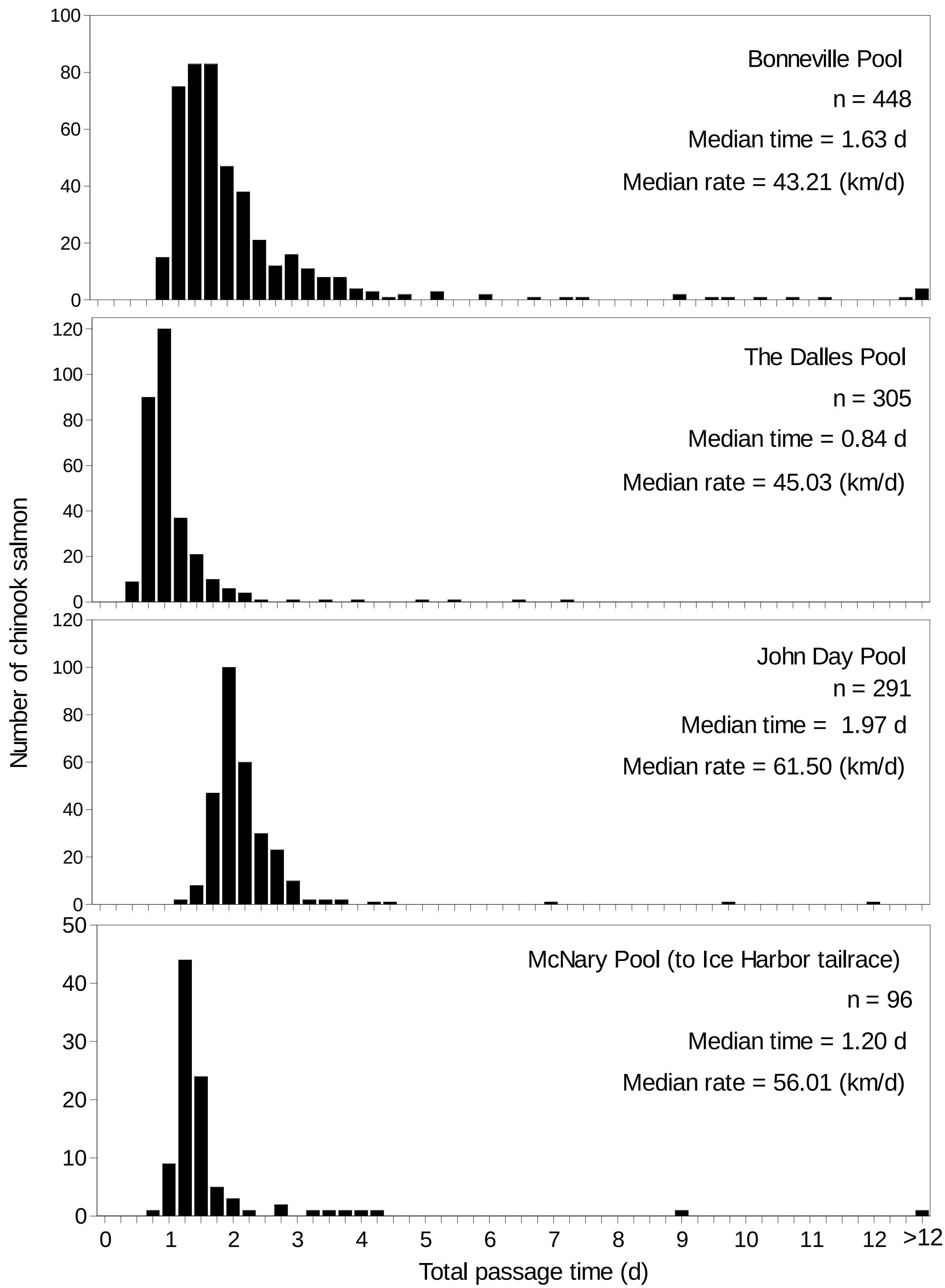

Figure 22. Number of chinook salmon and days to pass through the Bonneville, The Dalles, John Day and McNary pools in 1996. Times are from last record at the top of a ladder to first record at upstream tailrace and do not include fallback time.

Table 9. Median number of days to pass and median migration rates through the Bonneville, The Dalles, John Day and McNary pools in 1996. Number of radio-tagged spring and summer chinook salmon in parenthesis.

Bonneville Pool	The Dalles Pool	John Day Pool	McNary Pool[a]
Median days to pass through pool for all chinook salmon			
1.63 (448)	0.84 (305)	1.97 (291)	1.20 (96)
Median migration rate (km/d) through pool for all chinook salmon			
43.21	45.03	61.50	56.01
Median days to pass through pool for spring chinook salmon			
1.78 (349)	0.90 (217)	1.97 (192)	1.23 (79)
Median migration rate (km/d) through pool for spring chinook salmon			
39.66	41.97	61.38	54.77
Median days to pass through pool for summer chinook salmon			
1.28 (99)	0.72 (88)	1.96 (99)	1.06 (17)
Median migration rate (km/d) through pool for summer chinook salmon			
55.16	52.60	61.59	63.84

[a] Passage through McNary Pool was to the tailrace at Ice Harbor Dam.

Table 10. Number of radio-tagged spring and summer chinook salmon (in parenthesis) and median number of days to pass from the Bonneville Dam (BO) tailrace receiver site to exit from the top of McNary, Ice Harbor, Lower Granite and Priest Rapids ladders in 1996.

McNary	Ice Harbor	Lower Granite	Priest Rapids
Median days to pass from Bonneville Dam tailrace to top of ladder for all chinook salmon			
11.91 (269)	16.79 (97)	27.24 (80)	16.73 (101)
Median days to pass from Bonneville Dam tailrace to top of ladder for spring chinook salmon			
13.79 (185)	17.56 (81)	28.36 (66)	21.00 (32)
Median days to pass from BO tailrace to top of ladder for summer chinook salmon			
9.60 (84)	12.14 (16)	19.19 (14)	14.16 (69)

Although passage times were significantly different for spring and summer fish, passage times overall were weakly correlated with tagging date, with r^2 values of 0.15 to 0.31 for fish that passed McNary, Lower Granite and Priest Rapids dams and 0.03 for fish that passed Ice Harbor Dam (Figure 24). We did not observe large differences in passage time between spring- and summer-run fish per se, but rather a gradual decrease in passage time as the season progressed.

In 1996, chinook salmon with transmitters spent 57% of the total time to migrate from the Bonneville Dam tailrace to the tops of McNary and Ice Harbor dams passing the 4 or 5 dams (Figure 25).

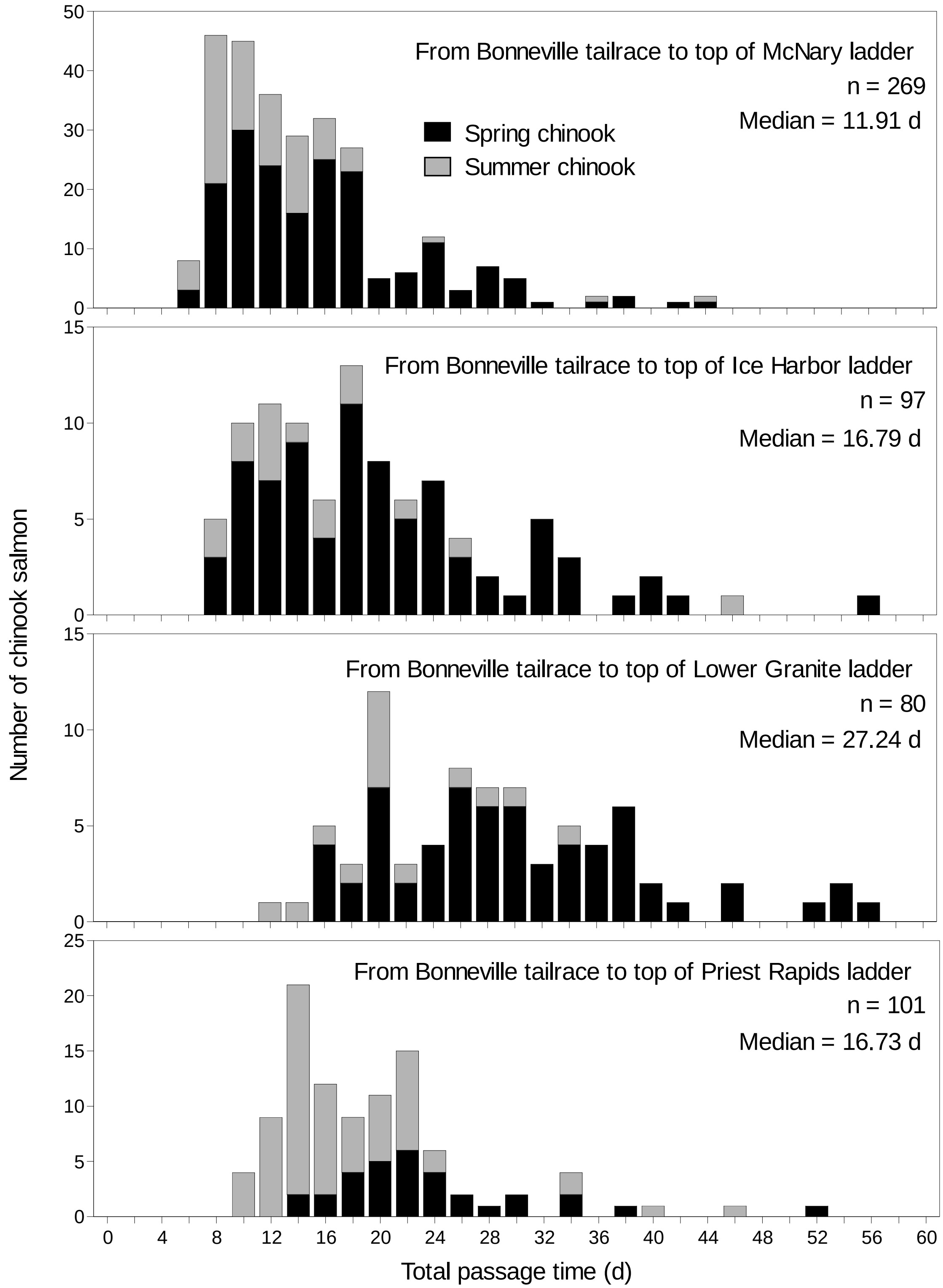

Figure 23. Number of spring and summer chinook salmon and days to pass from the Bonneville tailrace receivers to top-of-ladder receivers at McNary, Ice Harbor, Lower Granite and Priest Rapids dams in 1996. Fallback time included. (Also see Table 8.)

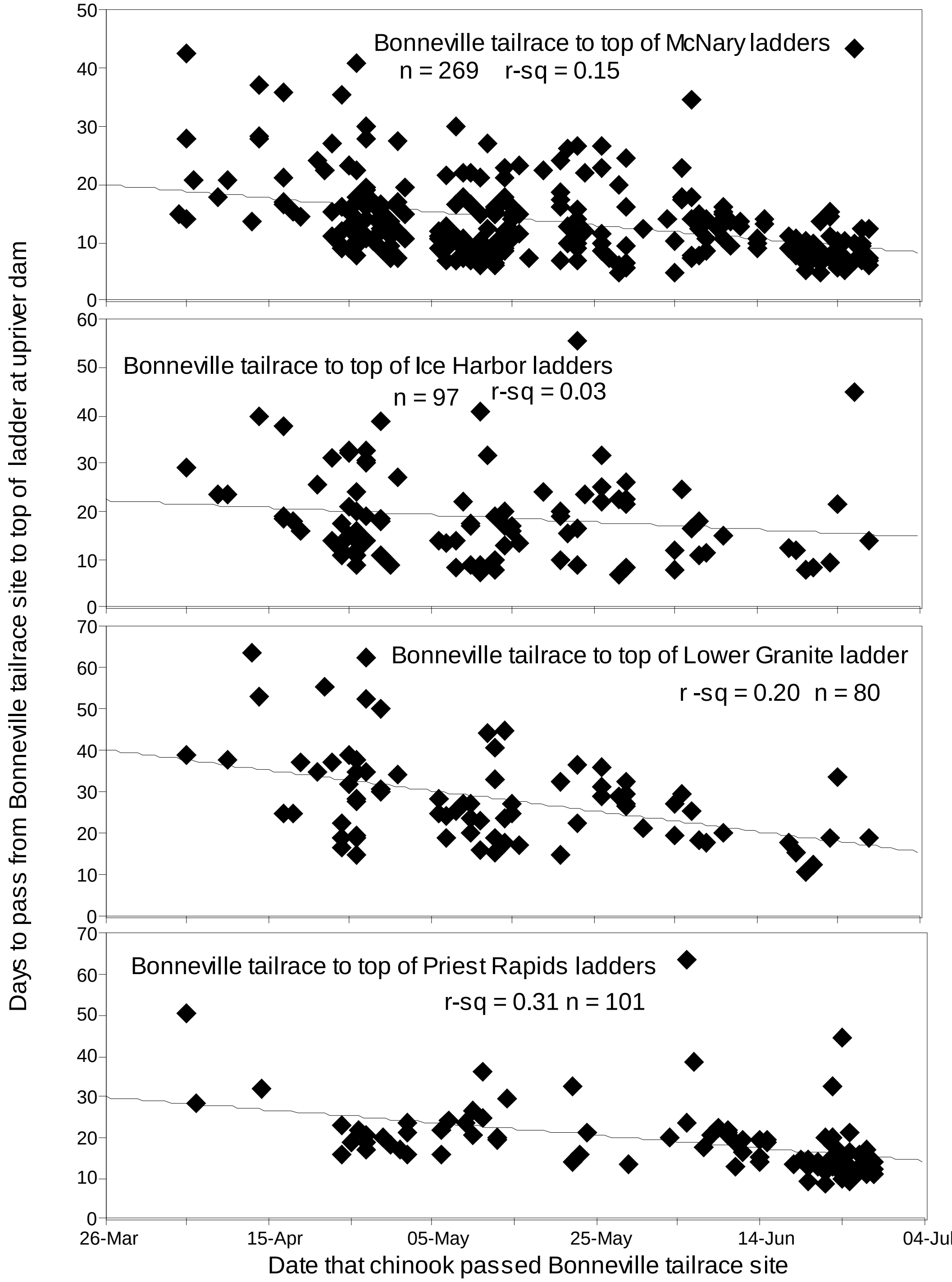

Figure 24. Days to pass from the Bonneville tailrace receivers to top-of-ladder receivers at McNary, Ice Harbor, Lower Granite and Priest Rapids dams, based on date that chinook salmon passed the Bonneville tailrace receiver.

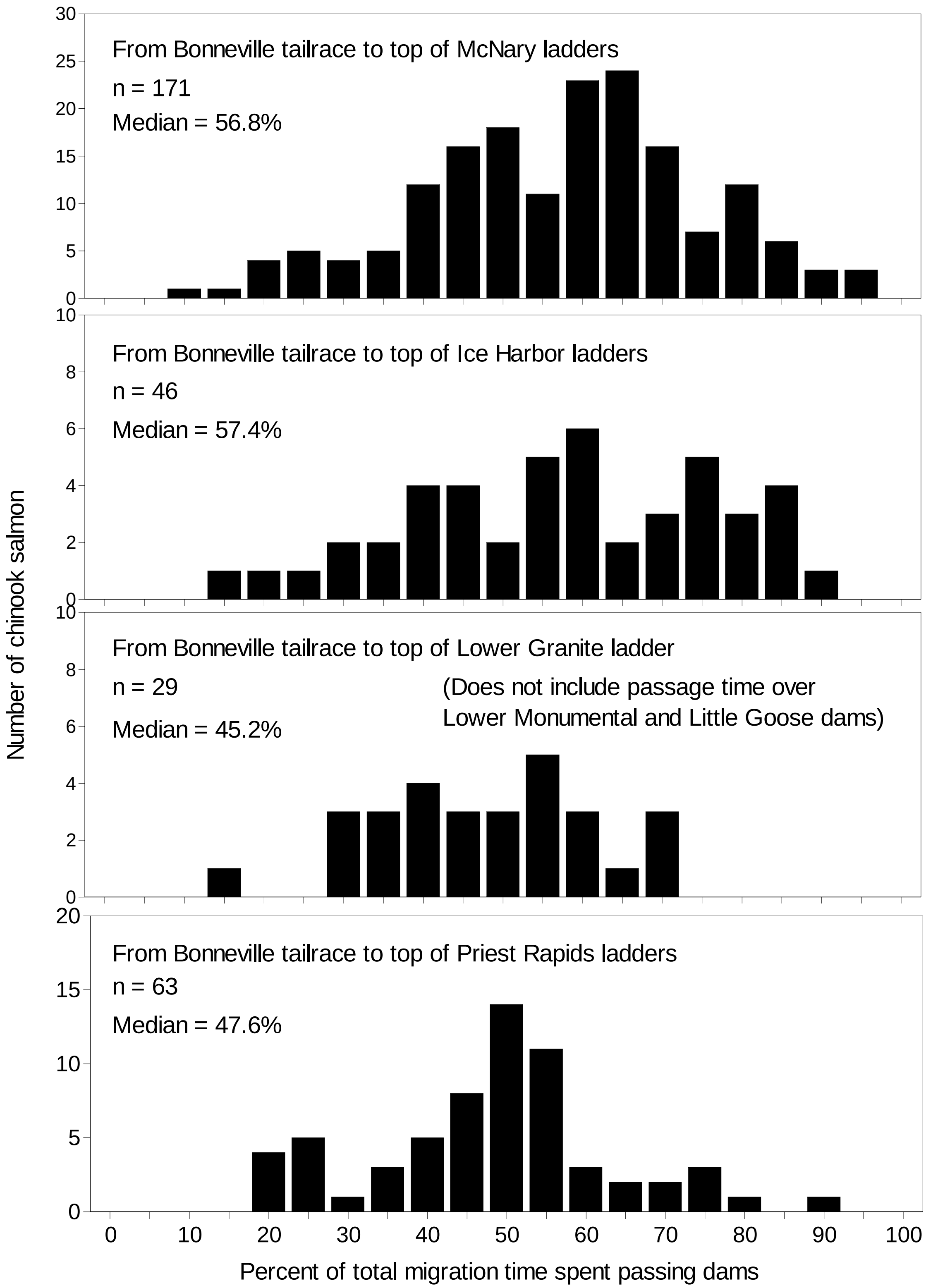

Figure 25. Number of chinook salmon and the percent of total passage time spent on first passage of dams (dam passage times after fallback not included) from Bonneville tailrace receivers to top-of-ladder receivers at McNary, Ice Harbor, Lower Granite and Priest Rapids dams in 1996.

For fish that migrated past Priest Rapids and Lower Granite dams, they spent 48% and 45% of the total migration time passing the 5 or 6 dams. Fish included in the analyses were those that had been recorded at the tailrace and top of ladders at each dam. For each of the groups of fish, we summed first passage time over each dam and then calculated the percentage of total passage time that was spent passing the dams. We did not include time spent reascending a dam after fallback events. The lower median percentage for fish that passed Lower Granite dam was at least partially because passage times at Lower Monumental andLittle Goose dams were not included in the sum of dam passage times.

The effect of cumulative time to pass the dams on total passage time to migrate to upriver dams was evident in regressions between sums of dam passage times versus total passage time from the Bonneville Dam tailrace. For each segment of the river analyzed, the slopes of the regression lines were near 1.0, and r^2 values were approximately 0.73 for fish that migrated to McNary, Ice Harbor and Lower Granite dams, and 0.91 for fish that migrated past Priest Rapids Dam (Figure 26). Points that fell farthest from the regression lines (long total passage time and relatively short summed passage times at dams) were mostly fish that fell back over dams one or more times and subsequently reascended. Multiple passages at a single dam were not included in the summed passage time. (See section on fallback at dams for additional information on the effects of fallbacks on passage times.)

Multivariate Analysis of Chinook Salmon Passage Times

We used multiple regression techniques to analyze upriver passage by chinook salmon in an attempt to determine which factors most influenced time to pass multiple projects. Based on all first records of fish at tailrace receivers, we were able to identify in-river environmental conditions at discreet points during upstream migration, including total flow, spill, and Secchi disk visibility. In some analyses, we also included the first date fish passed the Bonneville Dam tailrace site as an independent variable, both as a surrogate for water temperature and as an indicator for what portion of the run the fish was from. In additional analyses, we included the number of downstream fallback events by each fish, which can add several days to upriver passage (See section on the effects of fallback on passage time.) We also ran models that only included fish with no fallback events during their migration.

We used stepwise multiple regression models to test for significant variables affecting passage from the Bonneville Dam tailrace to the top of McNary, Lower Granite, and Priest Rapids dams, and from the Ice Harbor tailrace to the top of Lower Granite Dam. Because tailrace receiver efficiency was between 70% and 97% (Table 6), some upriver chinook salmon did not have tailrace records at every dam they passed. Sample sizes for the multiple regression models were generally less than 100, and as few as 35 radio-tagged fish.

We first tested passage of fish from the Bonneville Dam tailrace to the top of McNary Dam, with independent variables included for the date that each fish passed tailrace sites at Bonneville, The Dalles, John Day, and McNary dams (Model 1;

Table 11. Stepwise multiple regression model outputs for the time to pass for chinook salmon that did not fall back at any dam and migrated from the Bonneville Dam tailrace to the top of McNary Dam in 1996, including models run, variables retained, and standard procedure outputs. Environmental variables measured at date each fish passed tailrace sites at Bonneville (BO), The Dalles (TD), John Day (JD), and McNary (MN) dams.

Models Ru	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Variables:						
	BO flow	TD flow	JD flow	MN flow	BO tailrace date	
	BO spill	TD spill	JD spill	MN spill		
	BO Secchi	TD Secchi	JD Secchi	MN Secchi		
Model 1, All variables; 69 fish						
	a. BO tailrace date		0.0995	0.0995	7.40	0.0083
	b. JD Secchi depth		0.1561	0.0566	4.43	0.0392
	c. MN spill		0.2011	0.0449	3.66	0.0603
	d. TD flow		0.2662	0.0651	5.68	0.0201
	e. BO Secchi depth		0.3024	0.0362	3.27	0.0755
Model 2, All variables; 67 fish: removed 2 that passed in > 30 d						
	a. BO tailrace date		0.3200	0.3200	30.58	0.0001
	b. JD Secchi depth		0.3688	0.0488	4.95	0.0297
	c. BO Secchi depth		0.4208	0.0521	5.66	0.0203
	d. TD flow		0.4429	0.0221	2.46	0.1219
	e. MN Secchi depth		0.4649	0.0220	2.51	0.1185
Model 3, All variables *except* BO tailrace date; 69 fish						
	a. JD Secchi depth		0.0558	0.0558	3.96	0.0506
	b. MN spill		0.1152	0.0594	4.43	0.0391
	c. TD flow		0.1805	0.0653	5.18	0.0262
	d. MN flow		0.2451	0.0646	5.48	0.0224
	e. BO flow		0.2776	0.0325	2.83	0.0974
Model 4, All variables *except* BO tailrace date; 67 fish: removed 2 that passed in > 30 d						
	a. JD Secchi depth		0.0512	0.0512	3.51	0.0657
	b. MN Secchi depth		0.0910	0.0594	2.81	0.0988

Table 11). For the 69 fish that did not fall back at any location and had tailrace records at each dam, date at the Bonneville Dam tailrace was the first variable selected, with an r^2 value of 0.10 (Model 1; Table 11). Other variables selected as significant were Secchi disk depth at John Day Dam, spill at McNary Dam, flow at The Dalles Dam, and Secchi disk depth at Bonneville Dam for an overall r^2 value of 0.30. When we removed two fish with passage times longer than 30 d, variables that were significant were similar, but Secchi disk depth at McNary Dam was added, spill at McNary Dam was removed, and the overall r^2 value was higher at 0.44 (Model 2; Table 11). Secchi disk depth at John

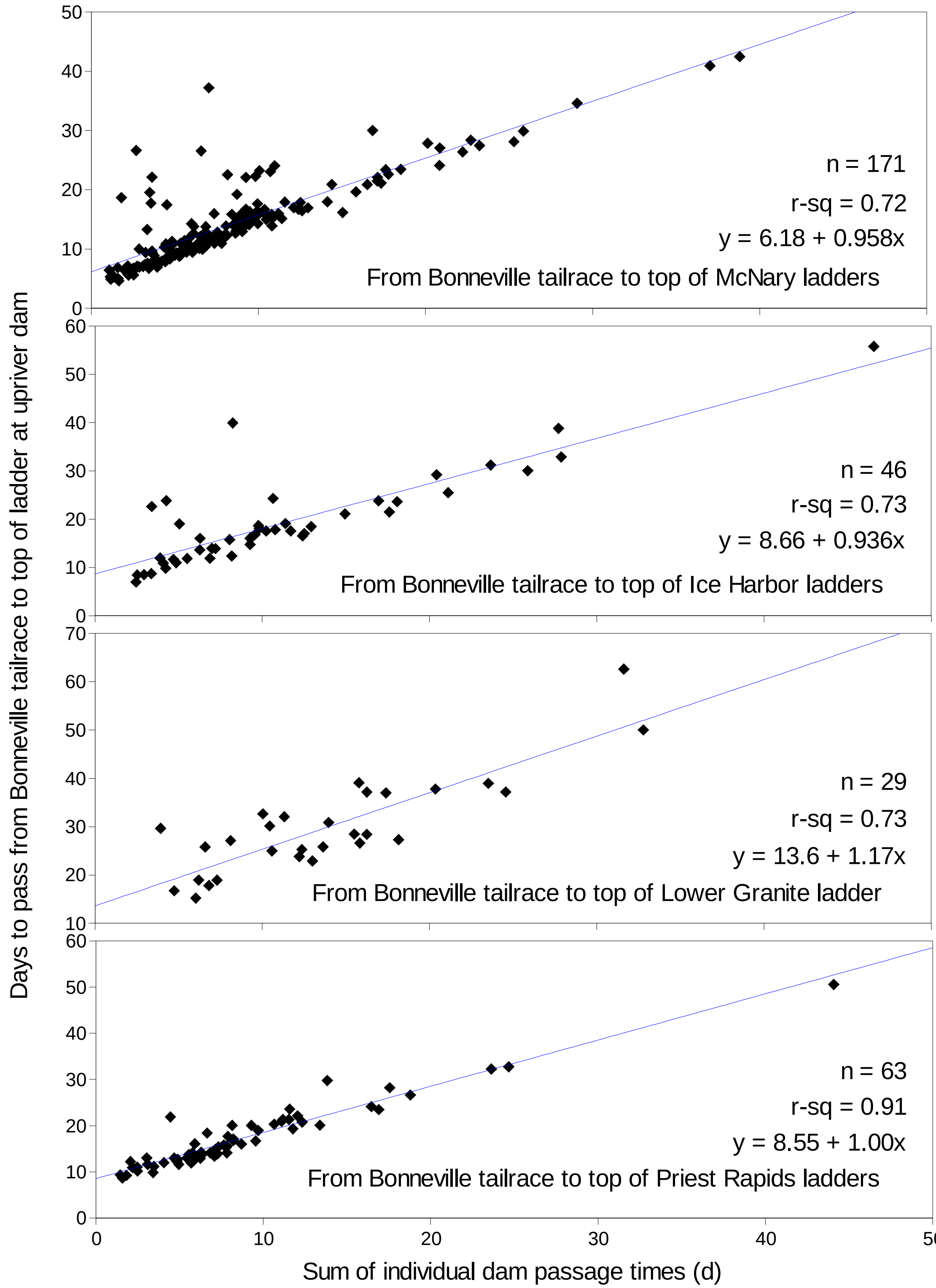

Figure 26. Sum of individual dam passage times and total time to pass from the Bonneville tailrace receivers to top-of-ladder receivers at McNary, Ice Harbor, Lower Granite and Priest Rapids dams for chinook salmon in 1996 (dam passage times after fallback not included).

Day Dam was selected as the most significant variable when we removed Bonneville Dam tailrace date, followed by spill at McNary Dam and flow at The Dalles, McNary, and Bonneville dams for an overall r^2 value of 0.28 (Model 3; Table 11). Removing the two fish with passage longer than 30 d reduced the overall r^2 to 0.09.

When we included chinook salmon that fell back and reascended at one or more dams prior to passing McNary Dam, the sample size increased to 87 fish. The number of fallbacks became the best predictor of passage time from the Bonneville Dam tailrace to the top of McNary Dam, with an r^2 of 0.15. Date at the Bonneville Dam tailrace was selected second, improving the r^2 to 0.24, followed by Secchi disk depth at Bonneville Dam, spill at McNary Dam, flow at The Dalles Dam, and Secchi disk depth at John Day Dam for an overall r^2 of 0.38 (Model 1; Table 12). When we removed three fish with passage times longer than 30 d, date at the Bonneville Dam tailrace became the best predictor with an r^2 of 0.32 (Model 2; Table 12). Number of fallbacks was second, improving the r^2 to 0.41, and with Bonneville Dam Secchi disk depth and The Dalles flow, the overall r^2 increased to 0.50. In an analysis with fallback fish, but without the number of fallbacks as an independent variable, date of fish at the Bonneville Dam tailrace was the best predictor with an r^2 of 0.15, and with Bonneville Dam Secchi disk visibility, John Day Secchi disk depth, The Dalles flow, and McNary spill, the overall r^2 was 0.27 (Model 3; Table 12). Without either the number of fallback events or the Bonneville Dam tailrace date as independent variables, no variables met the $P < 0.15$ criteria for model inclusion.

In another analysis we used records from fish that had good records at the tailrace of Bonneville Dam and at the top of McNary Dam to increase the number of fish in the analysis (268 fish). With environmental data for the dates that fish passed Bonneville and McNary dams, the date fish were at the Bonneville Dam tailrace, and the number of fallbacks at lower Columbia River dams, number of fallbacks was the best predictor of time to migrate with an r^2 value of 0.19 (Model 1; Table 13). Date at the Bonneville Dam tailrace, Bonneville Dam Secchi disk depth, McNary Dam Secchi disk depth, and Bonneville Dam spill were significant and increased the overall r^2 to 0.35. Without fallbacks as an independent variable, Bonneville Dam tailrace date was the best predictor ($r^2 = 0.15$), and Secchi disk depth and spill at the two dams increased the r^2 to 0.22 (Model 2; Table 13). Without either the tailrace date or the number of fallbacks, the r^2 was less than 0.07 with the other variables (Model 3; Table 13).

When we only included 215 chinook salmon that did not fall back at any lower Columbia River dams, date of passage at the Bonneville Dam tailrace was the best predictor, followed by Bonneville Dam Secchi disk depth, McNary Dam Secchi disk depth, and Bonneville Dam spill for an overall r^2 of 0.21 (Model 4; Table 13). Only Bonneville Dam Secchi disk depth was a significant predictor when we removed Bonneville Dam tailrace date from the model (Model 5; Table 13).

Secchi disk depth at Lower Granite Dam as the only significant variable ($r^2 = 0.36$) in an analysis of passage time for 40 fish that passed Lower Granite Dam, had tailrace records at both Ice Harbor and

Table 12. Stepwise multiple regression model outputs for the time to pass for chinook salmon that did or did not fall back at any dam and migrated from the Bonneville Dam tailrace to the top of McNary Dam in 1996, including models run, variables retained, and standard procedure outputs. Environmental variables measured at date each fish first passed John Day(JD), and McNary (MN) dams.

Variables:

BO flow	TD flow	JD flow	MN flow	BO tailrace date
BO spill	TD spill	JD spill	MN spill	Number of fallbacks
BO Secchi	TD Secchi	JD Secchi	MN Secchi	

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Model 1, All variables; 87 fish						
	a. Number of fallbacks		0.1529	0.1529	15.34	0.0002
	b. BO tailrace date		0.2416	0.0887	9.83	0.0024
	c. BO Secchi depth		0.2835	0.0419	4.85	0.0304
	d. MN spill		0.3067	0.0232	2.74	0.1015
	e. TD flow		0.3477	0.0410	5.09	0.0267
	f. JD Secchi depth		0.3768	0.0292	3.74	0.0565
Model 2, All variables; 84 fish: removed 3 that passed in > 30 d						
	a. BO tailrace date		0.3184	0.3184	38.31	0.0001
	b. Number of fallbacks		0.4085	0.0900	12.33	0.0007
	c. BO Secchi depth		0.4534	0.0449	6.57	0.0122
	d. MN Secchi depth		0.4771	0.0237	3.58	0.0623
	e. TD flow		0.4988	0.0172	2.74	0.1019
	F.	MN Secchi depth	0.5042	0.0118	1.87	0.1754
Model 3, All variables *except* number of fallbacks; 87 fish						
	a. BO tailrace date		0.1483	0.1483	14.80	0.0002
	b. BO Secchi depth		0.1972	0.0489	5.11	0.0263
	c. JD Secchi depth		0.2212	0.0240	2.56	0.1134
	d. TD flow		0.2414	0.0202	2.19	0.1431
	e. MN spill		0.2735	0.0321	3.58	0.0622
Model 4, All variables *except* number of fallbacks, BO tailrace date; 87 fish						
	No variables met the P < 0.15 criteria for inclusion in the model					

Lower Granite dams, and had no recorded fallback events (Model 1; Table 14). When we removed 5 fish that passed in more than 20 d, flow at Lower Granite Dam and spill at Ice Harbor Dam were the two best variables with an overall r^2 of 0.46 (Model 2; Table 14). We then substituted the first record at any Lower Granite receiver for tailrace records, to increase sample size. With 57 fish and all variables included, the stepwise model selected and then removed spill atLower Granite Dam, flow at Ice Harbor Dam, Ice Harbor tailrace date, and Ice Harbor Secchi depth for a model r^2 of 0.24 (Model 3; Table 14). With removal of 7 fish that passed in more than 20 d, flow at Lower Granite Dam and spill at Ice Harbor Dam were the only

Table 13. Stepwise multiple regression model outputs for the time to pass for chinook salmon that did or did not fall back and migrated from the Bonneville Dam tailrace to the top of McNary Dam in 1996, including models run, variables retained, and standard procedure outputs. Environmental variables measured at date each fish first passed the tailrace sites at Bonneville (BO) and McNary (MN) dams.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Variables:						
BO flow	BO spill	BO Secchi	BO tailrace date			
MN flow	MN spill	MN Secchi	Number of fallbacks			
Model 1, All variables; 268 fish						
	a. Number of fallbacks		0.1862	0.1862	60.86	0.0001
	b. BO tailrace date		0.2933	0.1071	40.17	0.0001
	c. BO Secchi depth		0.3162	0.0229	8.85	0.0032
	d. MN Secchi depth		0.3382	0.0220	8.75	0.0034
	e. BO spill		0.3454	0.0071	2.84	0.0929
Model 2, All variables *except* number of fallbacks; 268 fish						
	a. BO tailrace date		0.1495	0.1495	46.76	0.0001
	b. BO Secchi depth		0.1753	0.0258	8.29	0.0043
	c. BO spill		0.2043	0.0290	9.62	0.0021
	d. MN Secchi depth		0.2146	0.0103	3.46	0.0641
	e. MN spill		0.2233	0.0087	2.93	0.0880
Model 3, All variables *except* number of fallbacks, BO tailrace date; 57 fish						
	a. BO flow		0.0151	0.0151	4.09	0.0442
	b. BO spill		0.0317	0.0165	4.52	0.0344
	c. BO Secchi depth		0.0407	0.0091	2.49	0.1157
	d. MN flow		0.0488	0.0080	2.22	0.1371
	e. MN spill		0.0725	0.0238	6.72	0.0101
	f.	BO spill	0.0672	0.0054	1.52	0.2188
No fallback fish included						
Model 4, All variables; 215 fish						
	a. BO tailrace date		0.1211	0.1211	29.36	0.0001
	b. BO Secchi depth		0.1514	0.0302	7.55	0.0065
	c. MN Secchi depth		0.1943	0.0429	11.25	0.0009
	d. BO spill		0.2058	0.0115	3.04	0.0825
Model 5, All variables *except* BO tailrace date; 215 fish						
	a. BO Secchi depth		0.0113	0.0113	2.44	0.1197

variables retained, with an r^2 of 0.46 (Model 4; Table 14).

In our analysis of fish that migrated from the Bonneville Dam tailrace to Lower Granite Dam, few fish had good tailrace records at all six monitored dams, so we tried to maximize sample size by limiting environmental data to three dams. In the first series of models, we used

Table 14. Stepwise multiple regression model outputs for the time to pass for chinook salmon that did not fall back[a] and migrated from the Ice Harbor tailrace to the top of Lower Granite Dam in 1996, including models run, variables retained, and standard procedure outputs. Environmental variables measured at date each fish first passed tailrace receivers at Ice Harbor (IH) and Lower Granite (GR) dams (Models 1 and 2) or passed the Ice Harbor Dam tailrace and any receiver at Lower Granite Dam (Models 3 and 4).

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Variables:						
IH flow	IH spill	IH Secchi	IH tailrace date			
GR flow	GR spill	GR Secchi				
Only fish with tailrace records at Lower Granite included						
Model 1, All variables; 40 fish						
	a. GR Secchi depth		0.3579	0.3579	21.18	0.0001
Model 2, All variables; 35 fish: removed 5 that passed in > 20 d						
	a. GR flow		0.3821	0.3821	20.40	0.0001
	b. IH spill		0.4562	0.0742	4.36	0.0447
Fish with first GR record at any receiver included						
Model 3, All variables; 57 fish						
	a. GR spill		0.1208	0.1208	7.56	0.0081
	b. IH flow		0.1709	0.0501	3.27	0.0763
	C. IH tailrace date		0.2134	0.0425	2.86	0.0965
	D.	GR spill	0.2025	0.0109	0.74	0.3947
	E. IH Secchi depth		0.2354	0.0329	2.28	0.1370
Model 4, All variables; 50 fish: removed 7 that passed in > 20 d						
	a. GR flow		0.4106	0.4106	33.44	0.0001
	b. IH spill		0.4554	0.0448	3.86	0.0552

[a] passage behavior not monitored at Lower Monumental or Little Goose dams

environmental data for the date that each fish passed Bonneville, McNary, and Ice Harbor dams, as well as date the fish was first recorded at the Bonneville Dam tailrace, and the number of fallbacks. For 57 fish with tailrace records at the three dams, the number of fallback events was the best predictor ($r^2 = 0.28$) of passage time from the Bonneville Dam tailrace to the top of Lower Granite Dam (Model 1; Table 15). Bonneville Dam tailrace date, and flow, and Secchi disk depth at Ice Harbor Dam increased the overall r^2 to 0.53. When the number of fallbacks was removed as an independent variable, Bonneville Dam tailrace date was the best predictor, followed by spill at Ice Harbor Dam and Secchi disk depth at McNary Dam for a r^2 of 0.34 (Model 2; Table 15). A third model, without fallbacks or Bonneville Dam tailrace date, selected flow at Ice Harbor Dam and spill at McNary Dam as the best predictors (Model 3; Table 15).

Table 15. Stepwise multiple regression model outputs for the time to pass for chinook salmon that did or did not fall back and migrated from the Bonneville Dam tailrace to the top of Lower Granite Dam in 1996, including models run, variables retained, and standard procedure outputs. Environmental variables measured at date each fish first passed tailrace sites at Bonneville (BO), McNary (MN), and Ice Harbor (IH) dams.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Variables:						
BO flow	MN flow	IH flow	BO tailrace date			
BO spill	MN spill	IH spill	Number of fallbacks			
BO Secchi	MN Secchi	IH Secchi				
Model 1, All variables; 57 fish						
	a. Number of fallbacks		0.2837	0.2837	21.78	0.0001
	b. BO tailrace date		0.4509	0.1673	16.45	0.0002
	c. IH flow		0.5064	0.0554	5.95	0.0181
	d. IH Secchi depth		0.5314	0.0250	2.78	0.1016
Model 2, All variables *except* number of fallbacks; 57 fish						
	a. BO tailrace date		0.1878	0.1878	12.72	0.0008
	b. IH spill		0.2954	0.1076	8.24	0.0058
	c. MN Secchi depth		0.3396	0.0441	3.54	0.0653
Model 3, All variables *except* number of fallbacks, BO tailrace date; 57 fish						
	a. IH flow		0.0939	0.0939	5.70	0.0204
	b. MN spill		0.1591	0.0652	4.19	0.0456
No fallback fish included						
Model 4, All variables; 39 fish						
	a. IH flow		0.1192	0.1192	5.01	0.0314
	b. BO tailrace date		0.2352	0.1160	5.46	0.0251
	c. IH Secchi depth		0.3056	0.0704	3.55	0.0680
	d. MN spill		0.3942	0.0886	4.98	0.0324
	e. MN Secchi depth		0.4512	0.0570	3.43	0.0730
	f.	IH flow	0.4203	0.0309	3.13	0.1820
Model 5, All variables *except* BO tailrace date; 39 fish						
	a. IH flow		0.1192	0.1192	5.01	0.0314

For the 39 fish that had tailrace records at the three dams and no fallback events,flow at Ice Harbor Dam was the best predictor, followed by Bonneville Dam tailrace date, Secchi disk depth at Ice Harbor and McNary dams, and spill at McNary Dam to produce an r^2 of 0.42 (Model 4; Table 15). Removal of Bonneville Dam tailrace date as an independent variable left only flow at Ice Harbor Dam in the model, with an r^2 of 0.12 (Model 5; Table 15).

For another grouping of 61 fish that had good records at tailrace sites at Bonneville, McNary, and Lower Granite

Table 16. Stepwise multiple regression model outputs for the time to pass for chinook salmon that did or did not fall back and migrated from the Bonneville Dam tailrace to the top of Lower Granite Dam in 1996, including models run, variables retained, and standard procedure outputs. Environmental variables measured at date each fish first passed tailrace sites at Bonneville (BO), McNary (MN), and Lower Granite (GR) dams.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Variables:						
	BO flow	MN flow	GR flow	BO tailrace date		
	BO spill	MN spill	GR spill	Number of fallbacks		
	BO Secchi	MN Secchi	GR Secchi			
Model 1, All variables; 61 fish						
	a. Number of fallbacks		0.1895	0.1895	13.80	0.0005
	b. BO tailrace date		0.3153	0.1258	10.66	0.0018
	c. MN Secchi depth		0.3618	0.0465	4.15	0.0462
Model 2, All variables *except* number of fallbacks; 61 fish						
	a. BO tailrace date		0.1391	0.1391	9.53	0.0031
	b. MN Secchi depth		0.1998	0.0607	4.40	0.0403
Model 3, All variables except number of fallbacks, BO tailrace date; 61 fish						
	a. GR Secchi depth		0.0514	0.0514	3.20	0.0790
	b. McNary flow		0.0865	0.0351	2.23	0.1409
No fallback fish included						
Model 4, All variables; 41 fish						
	a. BO tailrace date		0.1191	0.1191	5.27	0.0272
	b. MN Secchi depth		0.1958	0.0767	3.63	0.0645
	c. MN spill		0.2757	0.0799	4.08	0.0507
Model 5, All variables *except* BO tailrace date; 41 fish						
	a. GR Secchi depth		0.0796	0.0796	3.37	0.0739

dams (Ice Harbor not included), the number of fallbacks and date at the Bonneville Dam tailrace were first selected, followed by Secchi disk depth at McNary Dam (Models 1 and 2; Table 16). Without fallbacks or date at Bonneville Dam tailrace, Secchi disk depth at Lower Granite Dam and flow at McNary Dam were retained with an r^2 of 0.08 (Model 3; Table 16). Forty-one fish did not fall back, and a stepwise model first selected date at the Bonneville Dam tailrace, followed by Secchi disk depth and spill at McNary Dam for a model r^2 of 0.28 (Model 4; Table 16). When date at Bonneville Dam tailrace was removed, only Secchi disk depth at Lower Granite Dam was retained (Model 5; Table 16).

The number of fallbacks was the best predictor of passage time from the Bonneville Dam tailrace to the top of Priest Rapids Dam for the 78 fish that had good tailrace records at Bonneville, McNary and Priest Rapids dams (Model 1; Table 17). Date at the Bonneville Dam tailrace and flow at Priest Rapids Dam were the second and third best variables, for an overall r^2 of 0.52. When we excluded the number of fallbacks in the analysis, date at the Bonneville Dam tailrace was the best predictor, and flow at McNary Dam was also retained by the model (Model 2; Table 17). Without the number of fallbacks or date at the Bonneville Dam tailrace, flow at McNary Dam and spill at Priest Rapids Dam were selected as the best predictors with an r^2 of 0.19 (Model 3; Table 17). For the 68 fish with no fallback events, date at the Bonneville Dam tailrace was the best predictor, followed by flow at Priest Rapids Dam and Secchi depth at Bonneville Dam (Model 4; Table 17). When we removed Bonneville Dam tailrace date from the model, flow and Secchi depth at Priest Rapids Dam were selected ($r^2 = 0.24$) (Model 5; Table 17).

For another grouping of 71 fish that had good records at Bonneville, John Day, and McNary tailrace sites, and migrated from Bonneville Dam to the top of Priest Rapids Dam, the number of fallbacks, date at the Bonneville Dam tailrace, and flow or spill at McNary Dam provided the best r^2 of 0.54 (Model 1; Table 18). Without fallbacks, date at Bonneville Dam tailrace, and spill at McNary Dam had an r^2 of 0.31. The next best was model 3 with flow and Secchi disk depth as the two variable and an r^2 of 0.18 (Model 3; Table 18). For the 62 fish that did not fall back, date at the Bonneville Dam tailrace, followed by Secchi disk depth at Bonneville Dam were the best variables with an r^2 of 0.39 (Model 4; Table 18). When date at Bonneville Dam tailrace was removed as a variable, flow and spill at McNary Dam, flow at John Day Dam, and spill at Bonneville Dam were significant with an overall r^2 of 0.34 (Model 5; Table 18).

Effects of Transition Pool Fallout on Passage Time

Chinook salmon behavior in fishways including entrance use, transition pool behavior, and passage time through portions of fishways have been summarized in Bjornn et al. (2000a). In that report, we described passage delays associated with transition pool behavior, and found significant delays occurred when fish exited transition pools into tailrace areas. Between 25% and 55% of the fish that passed Bonneville, McNary, Ice Harbor, or Lower Granite dams moved downstream from transition pools at the bottom of fish ladders into tailraces at those dams (Figure 27). At all monitored dams, median times to pass through transition pools were less than 2.5 h for all fish that did not fall out to the tailraces, but times were between 4 to 20 h for fish that fell out to the tailrace at Bonneville, McNary, Ice Harbor, or Lower Granite dams (Figure 27). In the context of general migration, we tested whether delays due to fallout at individual projects affected the overall time to pass several dams.

Fallout of transition pools at either Bonneville or McNary dams did not significantly ($P < 0.05$) lengthen mean passage time from the Bonneville Dam tailrace to the top of McNary Dam for the 215 chinook salmon with complete transition pool records at Bonneville and McNary dams (Figure 28). However, fish that fell out of the Bonneville transition pool had significantly ($P < 0.10$) longer median passage time than fish that did not fall out at either dam. For the 42 fish (20%) that fell out of transition pools at both Bonneville and McNary dams, mean and median time to pass between the two dams was significantly longer ($P < 0.05$)

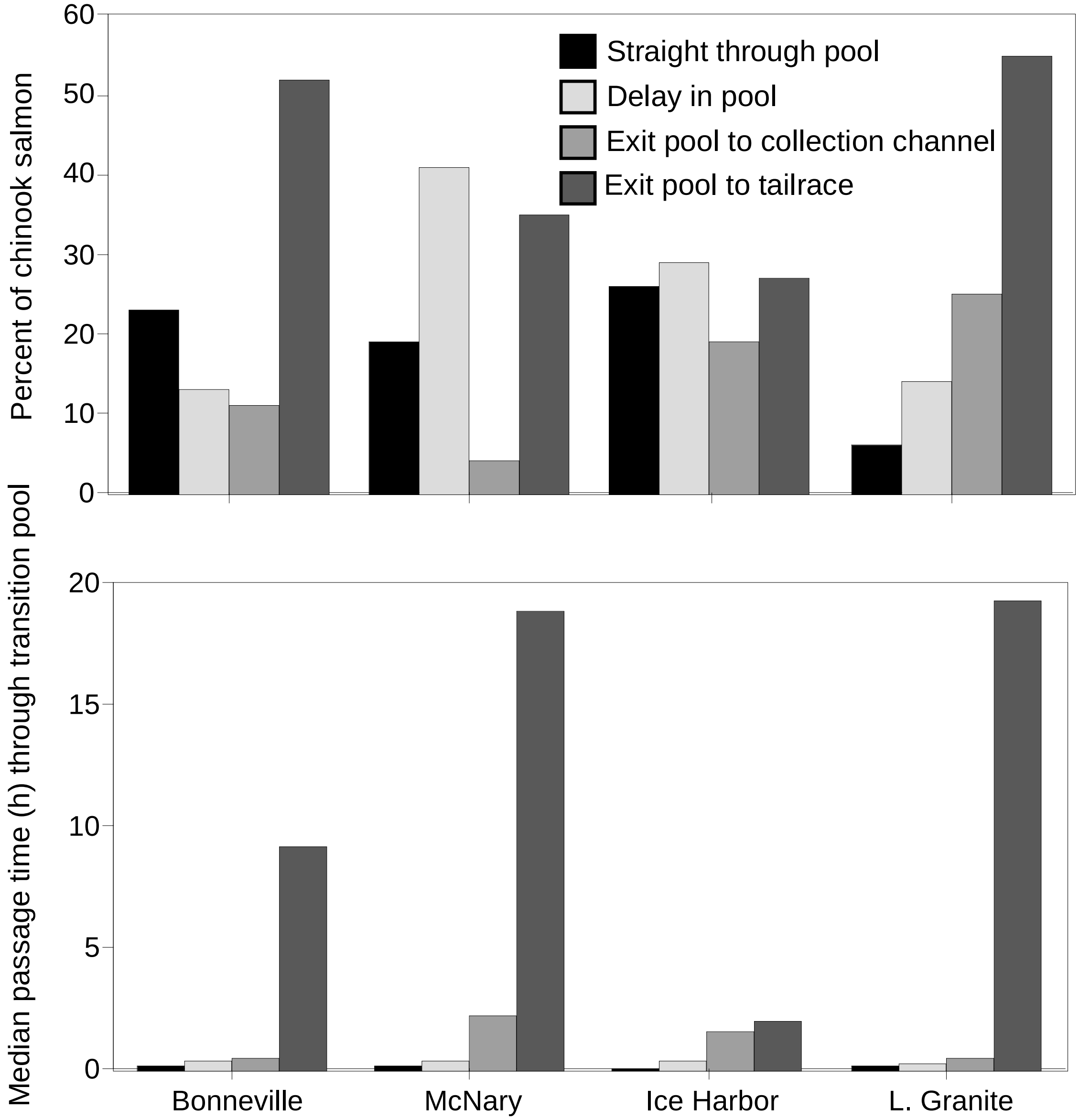

Figure 27. Percent of chinook salmon that moved straight through transition pools, were delayed temporarily, exited pools to collections channels, or exited pools into the tailrace (upper graph), and time to pass through transition pools at Bonneville McNary, Ice Harbor, and Lower Granite dams in 1996.

than for the 83 fish (39%) that did not fall out at either dam. Fifty-three chinook salmon had complete transition pool records at Bonneville, McNary, Ice Harbor, and Lower Granite dams. Mean and median passage times from the Bonneville Dam tailrace to the top of Lower Granite Dam increased with increased numbers of dams where fish fell out of transition pools (Figure 29), but the differences were not significant and power of the tests were low because of the small number of fish with transmitters that migrated past Lower

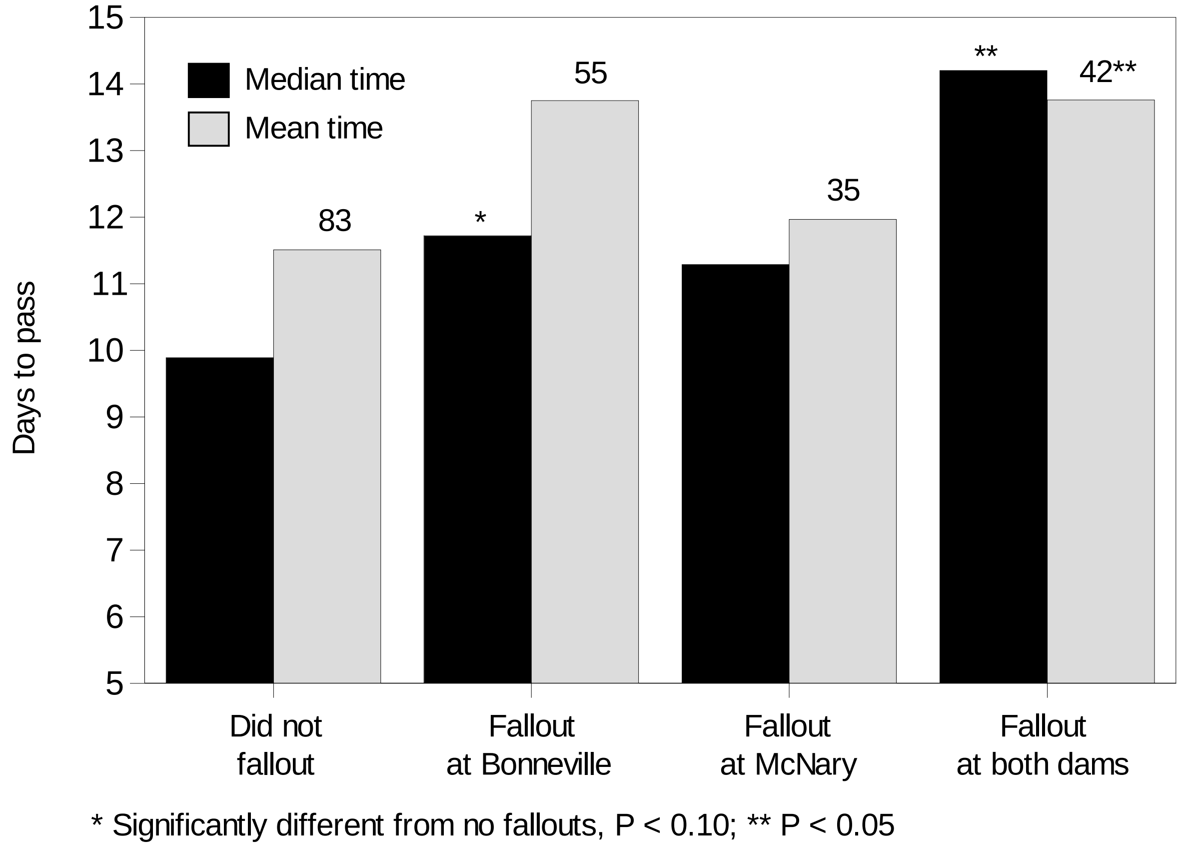

Figure 28. Mean and median time to pass (days) from the Bonneville Dam tailrace to the top of McNary Dam by chinook salmon that did or did not fall out of transition pools into tailraces at Bonneville and/or McNary dams in 1996. Number of fish in category above bars.

Granite Dam in 1996.

Fallback at Dams

Higher-than-average flows in 1996 resulted in nearly continuous spill at all study dams on the Columbia and Snake rivers during the spring and summer chinook salmon migration. In previous years, high levels of spill affected passage and increased fallback rates (Bjornn and Peery 1992), and we found similar trends in 1996. At least 185 chinook salmon with transmitters fell back at least once at one or more of the seven monitored dams,mostly over spillways, but a few through powerhouses, navigation locks, or ice and trash sluiceways in 1996. Of the 809 salmon known to have passed Bonneville Dam, 22.9% eventually fell back at one of the monitored dams. The 185 fish had 326 recorded fallback events, of which 133 (41%) were at Bonneville Dam. Most spring chinook salmon in 1996

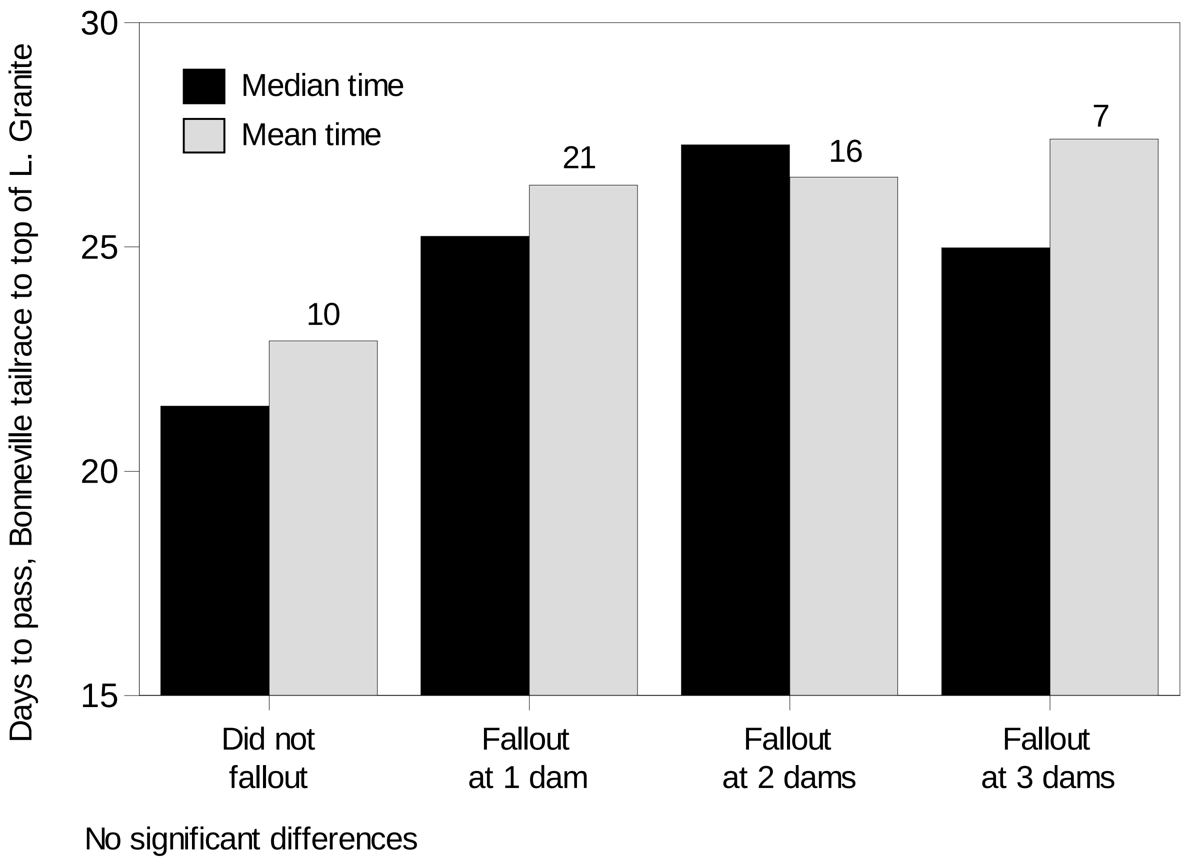

Figure 29. Mean and median time to pass from the Bonneville tailrace to the top of Lower Granite Dam by chinook salmon that did or did not fall out of transition pools into tailraces at Bonneville, McNary, Ice Harbor, and/or Lower Granite dams in 1996.

were bound for lower Columbia River tributaries and passed fewer dams than those going to upriver tributaries. A slightly higher percentage of spring chinook salmon (22.6%) fell back than summer chinook salmon (19.5%).

Of the 809 chinook salmon known to have passed Bonneville Dam, 77.1% did not fall back at any dam, 14.5% fell back once, 3.8% fell back twice, 2.6% fell back 3 times and 2.0% fell back four or more times.

The percentage of unique fish with transmitters that fell back over a dam ranged from 1% at Lower Granite Dam to 13.8% at Bonneville Dam (Table 19). About 13.3% percent of the fish that passed The Dalles Dam fell back and 12.5% fell back at John Day Dam. (Complete analyses of fallback behavior at Bonneville, The Dalles, and John Day dams were reported in Bjornn et al. 2000b, 2000c, and 2000d). Nine percent of the fish that passed McNary Dam fell back, 7.5% at Ice Harbor, and 5.2% at Priest Rapids dams. Standard 95% confidence intervals using the binomial approximation were +/- 2.3 to 3.5% for all dams except

Table 17. Stepwise multiple regression model outputs for the passage of chinook salmon that did or did not fall back from the Bonneville Dam tailrace to the top of Priest Rapids Dam in 1996, including models run, variables retained, and standard procedure outputs. Environmental variables measured at date each fish first passed Bonneville (BO), McNary (MN), and Priest Rapids (PR) tailrace sites.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Variables:						
	BO flow	MN flow	PR flow	BO tailrace date		
	BO spill	MN spill	PR spill	Number of fallbacks		
	BO Secchi	MN Secchi	PR Secchi			
Model 1, All variables; 78 fish						
	a. Number of fallbacks		0.2847	0.2847	30.25	0.0001
	b. BO tailrace date		0.4770	0.1923	27.58	0.0001
	c. PR flow		0.5224	0.0454	7.03	0.0098
Model 2, All variables *except* number of fallbacks; 78 fish						
	a. BO tailrace date		0.2398	0.2398	23.97	0.0001
	b. MN spill		0.3063	0.0666	7.20	0.0090
Model 3, All variables except number of fallbacks, BO tailrace date; 78 fish						
	a. McNary flow		0.1576	0.1576	14.22	0.0003
	b. Priest Rapids spill		0.1856	0.0280	2.58	0.1127
No fallback fish included						
Model 4, All variables; 68 fish						
	a. BO tailrace date		0.3631	0.3631	37.63	0.0001
	b. PR flow		0.4108	0.0477	5.26	0.0251
	c. BO Secchi depth		0.4351	0.0243	2.75	0.1022
Model 5, All variables *except* BO tailrace date; 68 fish						
	a. PR flow		0.1890	0.1890	15.38	0.0002
	b. PR Secchi depth		0.2413	0.0523	4.48	0.0381

Ice Harbor Dam, where the interval was +/- 5.5%. Fallback percentages did not reflect multiple fallbacks by individual fish or multiple passages past a dam and should not be used as correction factors for counts of fish passing ladders.

Fallback rates, the total number of fallback events divided by the number of unique chinook salmon with transmitters known to have passed a dam ranged from 1.0% at Lower Granite Dam to 18.3% at The Dalles Dam (Table 20). Fallback rates present a more complete picture of fallback behavior by chinook salmon, because multiple fallbacks by individual fish are represented. As with the percentage of unique fish that fallback, fallback rates should not be used to correct bias in counts of fish passing ladders caused by fallbacks. Rates do not account for fish that reascended the dam after each fallback at a dam. (See section adjusting counts of fish at ladders.) At Bonneville Dam, the fallback rate for fish

Table 18. Stepwise multiple regression model outputs for the time to pass for chinook salmon that did or did not fall back and migrated from the Bonneville Dam tailrace to the top of Priest Rapids Dam in 1996, including models run, variables retained, and standard procedure outputs. Environmental variables measured at date each fish first passed tailrace sites at Bonneville (BO), John Day (JD), and McNary (MN) dams.

Models run	Variables retained	Variables removed	r^2	Partial r^2	F	Prob. > F
Variables:						
	BO flow, BO spill, BO Secchi	JD flow, JD spill, JD Secchi	MN flow, MN spill, MN Secchi	BO tailrace date, Number of fallbacks		
Model 1, All variables; 71 fish						
	a. Number of fallbacks		0.3020	0.3020	29.86	0.0001
	b. BO tailrace date		0.5119	0.2099	29.23	0.0001
	c. MN flow		0.5363	0.0245	3.53	0.0645
Model 2, All variables *except* number of fallbacks; 71 fish						
	a. BO tailrace date		0.2462	0.2462	22.54	0.0001
	b. MN spill		0.3122	0.0660	6.52	0.0129
Model 3, All variables *except* number of fallbacks, BO tailrace date; 71 fish						
	a. MN flow		0.1479	0.1479	11.98	0.0009
	b. MN Secchi depth		0.1800	0.0321	2.66	0.1076
No fallback fish included						
Model 4, All variables; 62 fish						
	a. BO tailrace date		0.3548	0.3548	33.00	0.0001
	b. BO Secchi depth		0.3860	0.0312	2.99	0.0888
Model 5, All variables *except* BO tailrace date; 62 fish						
	a. MN flow		0.0984	0.0984	6.55	0.0130
	b. MN spill		0.2630	0.1646	13.18	0.0006
	c. JD flow		0.2909	0.0279	2.28	0.1362
	d. BO spill		0.3382	0.0473	4.08	0.0482

known to have passed the dam was 16.4%, at The Dalles Dam it was 18.3%, and at John Day Dam the rate was 14.6%. At McNary Dam the rate was 10.0%, at Ice Harbor Dam the rate was 8.3%, and at Priest Rapids Dam it was 5.2%.

A second fallback rate calculation was made based on the number of fallback events divided by the number of unique fish recorded at the tops of ladders at a dam (Table 20). This rate excluded fish that passed dams via navigation locks and those that were not recorded at the tops of ladders due to receiver outages or malfunctioning transmitters. These rates were from 0.2% to 2.7% higher than the rates calculated using the number known to pass each dam. We believe the most accurate fallback rate probably falls

Table 19. Number of unique chinook salmon with transmitters that fell back (FB) at dams, number known to have passed dams, number recorded at the tops of ladders at each dam and the percentage of fish that fell back at each dam in 1996.

Dam	Total that fell back at dam	Number known to pass dam	Recorded at top of ladder	FB percent of fish known to pass	FB percent of fish recorded
Bonneville	112	809	795	13.8	14.1
The Dalles	66	497	433	13.3	15.2
John Day	47	377	358	12.5	13.1
McNary	27	301	295	9.0	9.2
Ice Harbor	9	120	103	7.5	8.7
Lower Granite	1	101[a]	86	1.0	1.2
Priest Rapids	6	115	111	5.2	5.4

[a] Does not include 13 fish transported from Lower Granite trap to hatchery.

Table 20. Number of fallback (FB) events by chinook salmon with transmitters at dams, the number known to have passed dams, the number recorded at the tops of ladders at each dam and the fallback rate of fish at each dam in 1996.

	Total FB events at dam	Number known to pass dam	Recorded at top of ladder	FB rate of fish known to pass	FB rate of fish recorded
Bonneville	133	809	795	16.4	16.7
The Dalles	91	497	433	18.3	21.0
John Day	55	377	358	14.6	15.4
McNary	30	301	295	10.0	10.2
Ice Harbor	10	120	103	8.3	9.7
Lower Granite	1	101[a]	86	1.0	1.2
Priest Rapids	6	115	111	5.2	5.4

[a] Does not include 13 fish transported from Lower Granite trap to hatchery.

between the two rates presented. Standard 95% confidence intervals using the binomial approximation were +/- 2.2 to 3.6% for Bonneville and Lower Granite dams, +/- 3.4 to 4.2% for The Dalles, John Day, McNary, and Priest Rapids dams, and +/- 5.7% at Ice Harbor Dam.

Multiple fallbacks by individual chinook salmon occurred most frequently at The Dalles Dam, where 66 fish fell back 91 times: 9 fell back twice, 3 fell back three times and 2 fell back four or more times. At Bonneville Dam, 95 fish fell back once, 13 fish fell back twice and 4 fell back three times. At The Dalles Dam, 52 fell back once, 9 fell back twice, and 5 fell back 3 or more times. At John Day Dam, 40 chinook salmon fell back once, 6 fish fell back twice and 1 fish fell back three times; at McNary Dam, 24 fell back once, and 3 fell back twice. At Ice Harbor Dam, 8 fish fell back once and 1 fish fell back twice. No radio-tagged chinook salmon fell back multiple times at Lower Granite or Priest Rapids dams.

Chinook salmon with transmitters that fell back over dams in 1996 did so after a variety of movements upstream from the dams. Although we could not monitor the exact time that fish fell back we could usually estimate fallback times to within a few hours of the event using forebay, tailrace and fishway telemetry records. More than half of all fallback events at Bonneville and Ice Harbor dams occurred within 24 h of the fish passing over those dams (Table 21). A third or less fell back within 24 h at The Dalles, John Day, McNary, and Priest Rapids dams. Many chinook salmon migrated upriver and were recorded at fixed receivers at tributary sites or at upriver dams before they moved back downstream and fell back. Sixty-two percent of the events at The Dalles Dam, 47% of the events at McNary Dam and about 35% of the fallback events at Bonneville and John Day dams occurred after the fish was recorded upriver (Table 21). The remaining fallback events occurred more than 24 h after passing dams, but the fish were not recorded at receivers upriver from the dams.

At most dams monitored in 1996, more fish passed via ladders on the south-shore than via north-shore ladders. Exceptions were Lower Granite Dam, which only has a ladder at the south shore, and Priest Rapids Dam, where ladders were on the East and West shores (Table 22).

Fallback percentages varied considerably for different ladders, but at all dams except Priest Rapids the fallback percentage was higher for fish that passed via the south-shore ladder. At Bonneville Dam, 21.7% of the fish that were recorded at the top of the Bradford Island ladder near the south shore fell back, compared to 5.3% that fell back after passing via the north-shore ladder. At The Dalles Dam, 18.1% of fish recorded passing via the south-shore ladder and 11.8% of those recorded passing the north-shore ladder, adjacent to the spillway, eventually fell back (Table 22). At John Day Dam 13.5% of the fish that passed via the south-shore ladder and 10.3% of those that passed via the north-shore ladder, adjacent to the spillway, fell back. At McNary Dam 11.0% of the fish that passed via the south-shore and 6.7% of the fish that passed via the north-shore ladder fell back. At Ice Harbor Dam, 11.0% that passed via the south-shore ladder and 6.3% that passed via the north-shore ladder fell back. At Priest Rapids Dam, 3.5% that passed via the east-shore ladder and 10.7% that passed via the west-shore ladder fell back (Table 22).

We also calculated the percentage of fallback events by chinook salmon with transmitters based solely on the ladder passed, without regard for the disproportionate numbers of fish that passed via south-shore ladders. Chinook salmon passed via south-shore ladders prior to 70% to 84% of all fallback events at the lower Columbia River dams and at Ice Harbor Dam (Table 23). When we only considered fallbacks that occurred within 24 h of passing these dams, 60% to 94% of chinook salmon passed via south-shore ladders prior to the fallback event (Table 23).

Table 21. Number of fallback (FB) events by chinook salmon with transmitters at dams in 1996, the number and percent that fell back within 24 h of passing dams, the percent recorded upriver before they fell back and the percent that fell back more than 24 h after passing but were not recorded upstream.

	Total FB events at dam	Number that FB in <24 h	Percent that FB in <24 h	Percent recorded upriver	Percent that FB in >24 h
Bonneville	133	72	54	35	11
The Dalles	91	21	26	62	13
John Day	55	14	25	36	38
McNary	30	10	33	47	20
Ice Harbor	10	6	60	10	30
Lower Granite	1	--	--	--	100
Priest Rapids	6	2	33	n/a	67

Table 22. Number of unique chinook salmon with transmitters recorded at the tops of south-shore and north-shore ladders at each dam, the number of unique fish that fell back (FB), and the percentage of fish that passed each ladder and fell back at each dam in 1996.

	South-shore ladder			North-shore ladder		
	Unique fish at top of ladder[a]	Unique fish that fell back	% past ladder that FB	Unique fish at top of ladder[b]	Unique fish that fell back	% past ladder that FB
Bonneville	429	93	21.7	416	22	5.3
The Dalles	304	55	18.1	153	18	11.8
John Day	288	39	13.5	78	8	10.3
McNary	164	18	11.0	134	9	6.7
Ice Harbor	73	8	11.0	32	2	6.3
Lower Granite	86	1	1.2	---	---	---
Priest Rapids[a]	85	3	3.5	28	3	10.7

[a] ‘South’ ladder at Priest Rapids Dam is on east side of Columbia River.
[b] ‘North’ ladder at Priest Rapids Dam is on west side of Columbia River.

The percentages of fish that passed via south-shore ladders prior to falling back were similar for all events and events within 24 h at The Dalles, John Day and Ice Harbor dams (Table 23). At Bonneville Dam, however, 94% of the fallback events that occurred within 24 h were by fish that passed via the Bradford Island ladder (south- shore), compared to 82% of all fallback events at the dam. Fish that passed over Bonneville Dam via the Bradford Island ladder fell back at a higher

Table 23. Number of total fallback (FB) events and fallback events within 24 h of passing each dam by chinook salmon with transmitters, and the percentage of fallback events by fish using the south-shore or north-shore ladders at each dam in 1996.

	All fallback events			Fallback events within 24 h		
	Number of events	Percent south ladder[a]	Percent north ladder[b]	Number of events	Percent south ladder	Percent north ladder
Bonneville	133	82	17	72	94	6
The Dalles	91	73	24	23	70	30
John Day	55	84	15	14	86	14
McNary	30	70	30	10	60	40
Ice Harbor	10	80	20	6	83	17
Lower Granite	1	100	---	---	---	---
Priest Rapids[a]	6	50	50	2	50	50

[a] 'South' ladder at Priest Rapids Dam is on east side of Columbia River.
[b] 'North' ladder at Priest Rapids Dam is on west side of Columbia River.

rate than for all other dams and ladders monitored in 1996. The ladder was unique among all dams in that the top of the ladder was on an island. Based on mobile-tracking of chinook and sockeye salmon with transmitters in 1997 and 1998, many fish that exit the Bradford Island ladder follow the Bradford Island shoreline into the forebay of the spillway and subsequently fall back over the dam (Bjornn et al. 1999a).

Escapements Past Dams Based on Adjusted Counts of Salmon at Dams

Counts of salmon and steelhead that pass up the ladders at the dams are used as indices of abundance of the runs at that point in their migration. The counts are indices of upriver escapement, rather than complete counts, because some fish pass the dams via the navigation locks, and because fish that fall back over the dams and do or do not reascend over the dam add a positive bias to the counts. Adjustment of the counts for fish that pass through the navigation locks and for fallbacks at Columbia and Snake river dams has been calculated only when adult tagging studies have been conducted. In previous studies, fallback rates varied among species and years, with river flow and spill at dams, as well as with the configuration of top-of-ladder exits at specific dams (Bjornn and Peery, 1992; Liscom et al, 1979). In 1996, we used fallback and reascension rates for adult chinook salmon with transmitters to calculate adjustment factors for all monitored dams. Adjustments were then applied to salmon counted in the ladders and reported in the Annual Fish Passage Report published by the Corps (USACE, 1996).

We believe the most accurate estimate of escapement past the dams includes counts of salmon in the ladder at the dams, the number of fish that fall back, the number that reascend through the ladders, and the number of fish that pass upstream through the navigation locks.

Fallback of salmon at the dams and reascension through ladders creates a positive bias in the number of fish counted as they pass up the ladders, while passage through the navigation lock is unaccounted for in counts of fish passing up the ladders. Fish that pass through the lock compensate for the positive bias in fish counts due to fallback and reascension, but the amount of compensation depends on the number of fallbacks and the number of fish passing through the lock.

We estimated escapement of fish past dams by calculating adjustment factors based on passage of fish with transmitters and then applied adjustments to the total number of fish counted at the dam. The first adjustment factor (AF) was calculated by the formula:

$$AF_1 = (LP_K + NLP_K - FB_{UF} + R_{UF}) / TLP_K$$

where:

- LP_K was the number of unique fish with transmitters known to have passed the dam via the ladders (assumes that unrecorded fish passed dam via ladder),
- NLP_K was the number of unique fish with transmitters known to have passed the dam via the navigation lock,
- FB_{UF} was the number of unique fish that fell back at the dam one or more times,
- R_{UF} was the number of unique fish that reascended the dam and stayed upstream from the dam regardless of the number of times it fell back, and
- TLP_K was the total number of times unique fish with transmitters were known to have passed the dam via ladders (includes initial and all reascensions).

The TLP_K term was the count of radio-tagged chinook salmon equivalent of the total USACE count of salmon that passed through the ladders. When adjustment factor AF was applied to the counts of salmon that passed through the ladders, the adjusted number approximated the total escapement past dams. If the NLP term, passage through the navigation lock, was not available, the adjusted number was an underestimate of the escapement by the number of fish that passed through the navigation lock. Less than 1% of chinook salmon with transmitters passed Bonneville Dam via the navigation lock in 1996.

Estimates of escapement derived from the adjustment factors were based on the assumption that fish with transmitters were good surrogates for the remainder of the fish in the run passing the dam. We calculated adjustments AF using pooled data for the entire range of passage by chinook salmon with transmitters. If there was temporal variability in fallback and reascension rates or the tagged fish were not representative of the run then the adjustment factors based on pooled data may be biased. Pooled adjustment factors were 0.863 at Bonneville Dam, 0.845 at The Dalles Dam, 0.869 at John Day Dam, 0.907 at McNary Dam, 0.926 at Ice Harbor Dam, 0.989 at Lower Granite Dam and 0.950 at Priest Rapids Dam (Table 24).

We also calculated adjustment factors using a stratified sampling method that calculated factors for consecutive 5 d blocks during the time that radio-tagged chinook salmon were passing dams. Each block was weighted by the total

Table 24. Unique fish with transmitters known to have passed the dams via ladders (LP_K) and navigation lock (NLP_K), unique fish that fell back one or more times (FB_{UF}), unique fish that reascended (R_{UF}), total number of times fish with transmitters were known to have passed through ladders (TLP_K), and pooled fish count adjustment factors (AF) for spring and summer chinook salmon with transmitters at monitored Columbia and Snake river dams in 1996.

Dam	LP_K[a]	NLP_K	FB_{UF}	R_{UF}	TLP_K	pooled AF
Bonneville[a]	804	5	112	100	924	0.863
The Dalles	498	n/a	66	36	554	0.845
John Day	378	n/a	47	28	413	0.869
McNary	302	n/a	27	9	313	0.907
Ice Harbor	115	n/a	9	7	122	0.926
Lower Granite	89	n/a	1	1	90	0.989
Priest Rapids	115	n/a	6	6	121	0.950

[a] Includes fish that passed dam unrecorded.

number of chinook salmon counted passing ladders during that block. Weighted AF values differed from pooled values by +/- 0.004 to 0.008 at the lower Columbia River dams, 0.010 at Ice Harbor Dam, 0.002 at Lower Granite Dam, and 0.021 at Priest Rapids Dam, an indication that our sample of tagged fish was representative, and that temporal variation in fallback and reascension rates were relatively minor. The only exception was Priest Rapids Dam, where the weighted factor was considerably lower than the pooled value. The difference was most likely caused by under representation of the latter portion of the summer chinook salmon run; one fish out of five that passed in the final block of radio-tagged fish produced a block adjustment of 0.80 that was weighted heavily because a relatively large number of untagged fish passed the dam during the 5 d block.

Escapements of salmon past dams were calculated by multiplying fish counts reported by USACE by pooled adjustment factors (Figure 30; Table 25). In 1996 the USACE adult spring and summer chinook salmon count at Bonneville Dam was 67,527 fish. The adjusted count using the pooled AF at Bonneville Dam was 58,276, with a positive bias of 9,251 fish (15.9%) (Table 25).

Estimated positive biases in the 1996 USACE counts of adult spring and summer chinook salmon at other monitored dams were not as large as at Bonneville Dam, but were significant nonetheless (Table 25). Positive biases as a proportion of the adjusted count at The Dalles and John Day dams were similar to or higher than the proportion at Bonneville Dam. Using the pooled AF, the positive bias was about 5,700 fish (18% of the adjusted count) at The Dalles Dam, about 4,000 fish at John Day Dam (15%), about 2,600 fish at McNary Dam (10%), about 690 fish at Ice Harbor Dam (8%), about 80 fish at Lower Granite Dam (1%) and about 670 fish at Priest Rapids Dam (5%) (Figure 30). Biases calculated with weighted adjustment factors were within 6% (< 300 fish) of pooled results at the

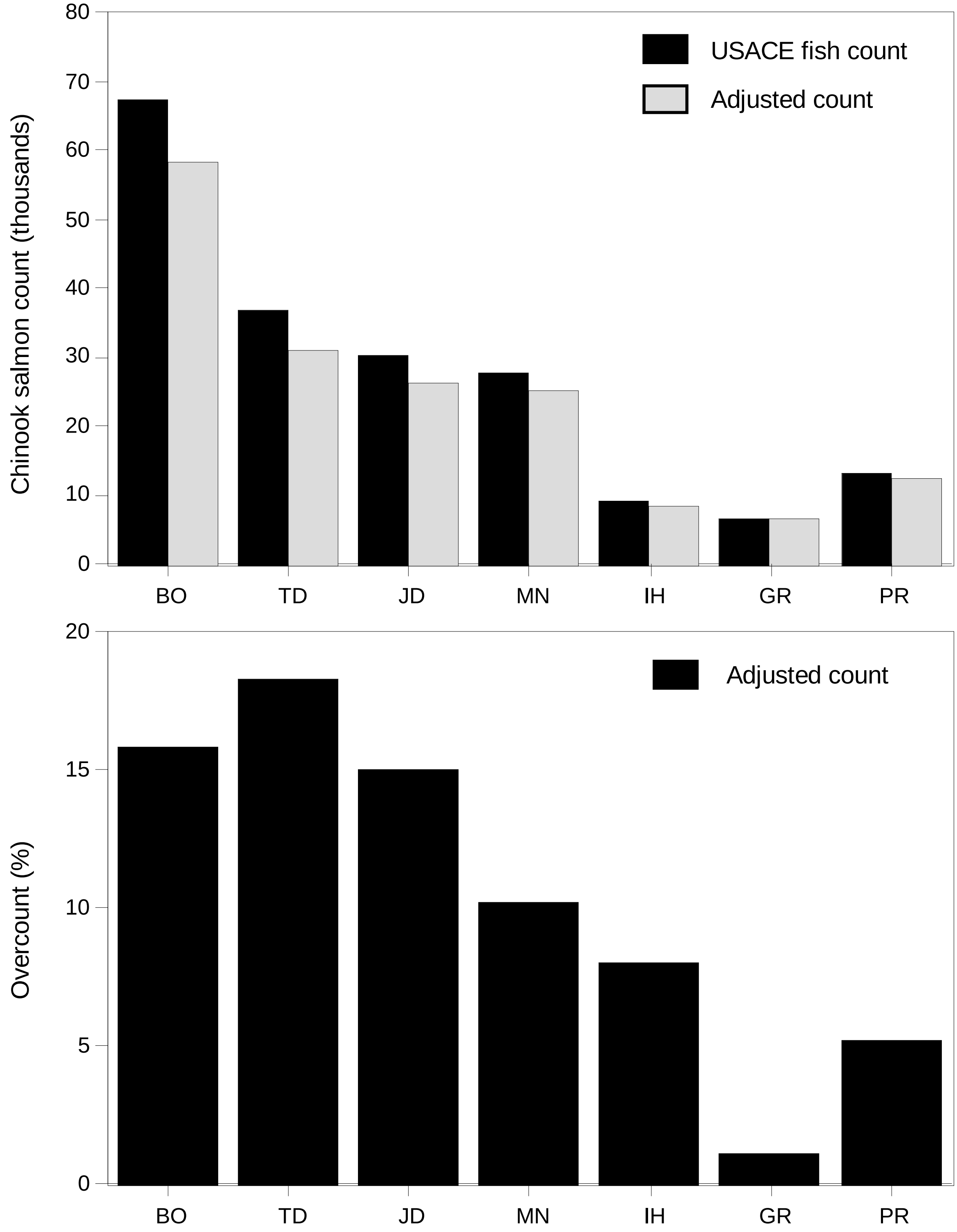

Figure 30. USACE counts of adult chinook salmon passing ladders in 1996, with estimated escapements using fallback and reascension rates (top). Percent of bias in USACE counts of salmon as an index of escapement based on adjustment factors (bottom).

Table 25. Reported USACE counts of adult spring and summer chinook passing through ladders at monitored dams, estimated escapements using pooled adjustment factors, 95% confidence intervals, and bias in the counts in 1996 as escapement indices.

	USACE ladder escapement	Pooled adjustment Estimated escapement	Pooled adjustment Bias	Weighted escapement bias
Bonneville	67,527	58,276 (+/- 1,486)	9,251	8,981
The Dalles	36,900	31,181 (+/- 1,107)	5,720	5,941
John Day	30,481	26,488 (+/- 1,006)	3,993	3,749
McNary	27,673	25,099 (+/- 886)	2,574	2,435
Ice Harbor	9,250	8,566 (+/- 425)	685	592
Lower Granite	6,823	6,748 (+/- 150)	75	89
Priest Rapids	13,300	12,635 (+/- 519)	665	944

lower Columbia River dams and about 15% (< 100 fish) at the Snake River dams (Table 25). The weighted bias was 944 fish for Priest Rapids Dam, about 1.4 times the pooled bias.

Effect of Flow, Spill, Turbidity, and Dissolved Gas on Fallbacks

Peak discharge and total flow volumes during the 1996 spring and summer chinook salmon migration were similar at the four lower Columbia River dams, but spill rates differed considerably between dams. During most of the spring and summer chinook salmon migration, spill at Bonneville and McNary dams was about 45% of total flow; spill at The Dalles Dam was about 63% of total flow, and at John Day Dam spill was about 20% of total flow. In previous studies (see Bjornn and Peery, 1992) fallback rates have increased with increased flow and spill at dams. In 1996, we examined relationships between fallback rates and flow, spill, and turbidity data using chinook salmon with transmitters at monitored dams with a variety of methods, although analyses have focused on lower Columbia River dams where fallback rates were the highest (see Bjornn et al. 2000b, 2000c, and 2000d for detailed reports on fallback at Bonneville, The Dalles, and John Day dams).

Although the number of chinook salmon with transmitters recorded daily at each dam was similar proportionately to daily counts of salmon at the count windows in the ladders (Figure 31), low numbers of radio-tagged fish passed on some days and made tagged fish/counted fish ratios variable, particularly at upriver dams where small numbers of radio-tagged fish were recorded. When we used daily fallback events/daily counts of salmon as a measure of the proportion of chinook salmon that fell back on a daily basis, we found that fallback events appeared to increase when total flow and spill increased, but the r^2 values were low (Figures 32 and 33). At all four lower Columbia River dams there appeared to be an increase in the proportion of fish that fell back when flows exceeded about 350 kcfs (Figure 32). Similar thresholds

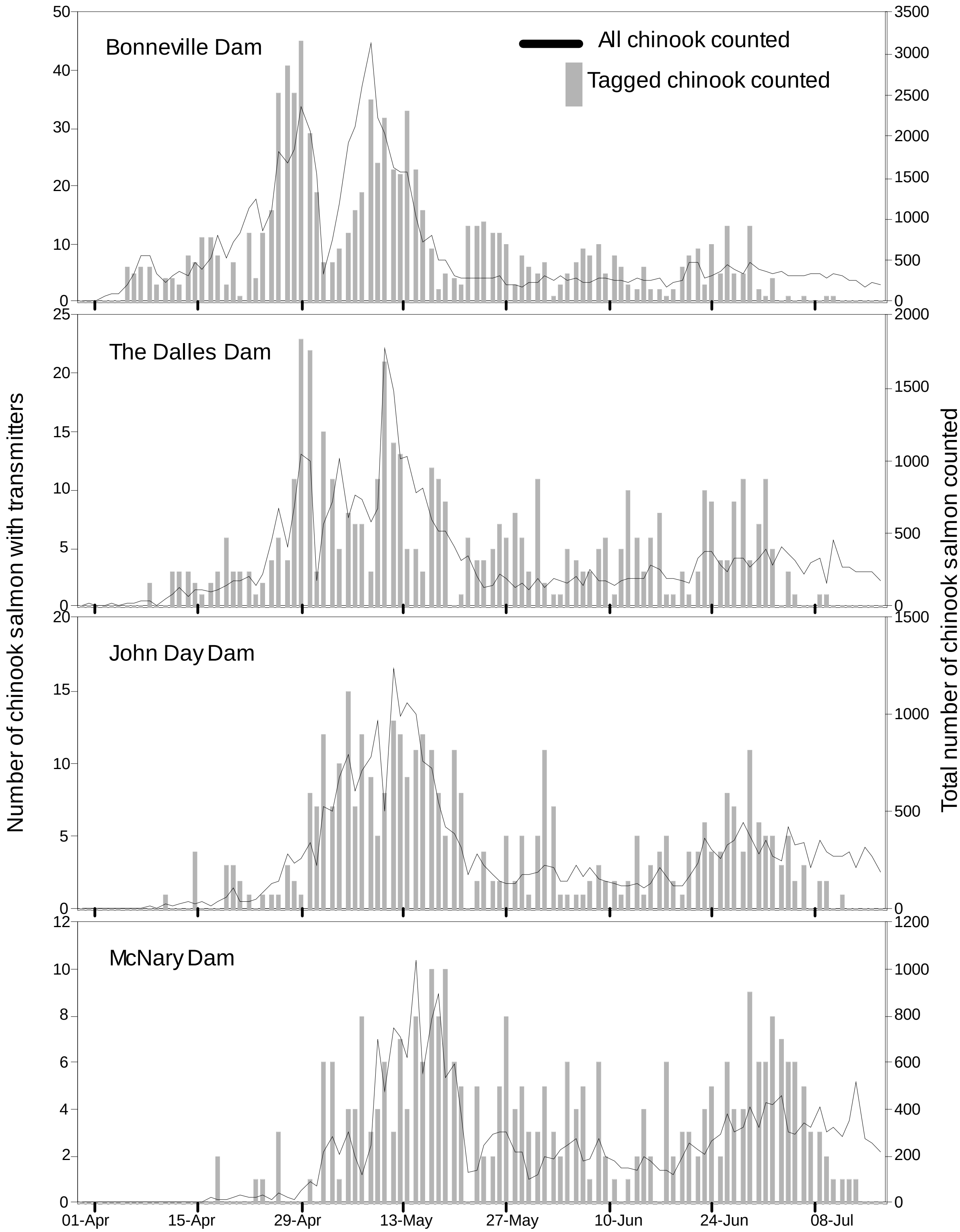

Figure 31. Daily chinook salmon counts and the number of chinook salmon with transmitters that passed Bonneville, The Dalles, John Day, McNary, Priest Rapids, Ice Harbor, and Lower Granite dams in 1996.

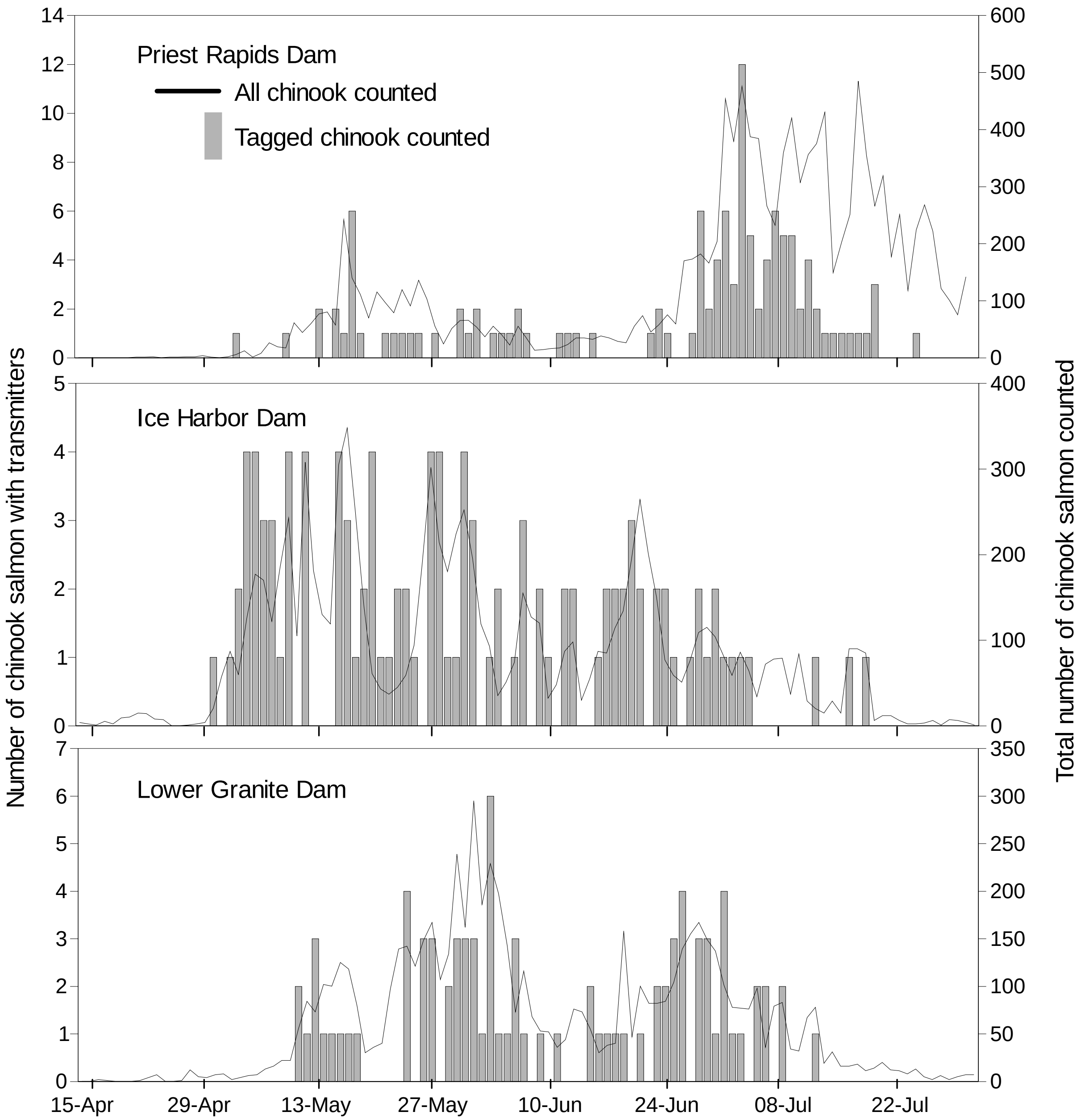

Figure 31. Continued.

appeared to occur at Bonneville Dam when spill exceeded 200 kcfs and at John Day Dam when spill exceeded 100 kcfs, but those relationships were not well defined (Figure 33). All fallback events were included in this analysis, although many fish had migrated upriver to tributary sites or other dams before falling back.

We also calculated daily fallback/daily passage ratios for radio-tagged fish only. This method increased the variability of fallback ratios (values up to 100%), particularly on days when few radio-tagged fish passed dams but one or more fell back. To moderate the influence of

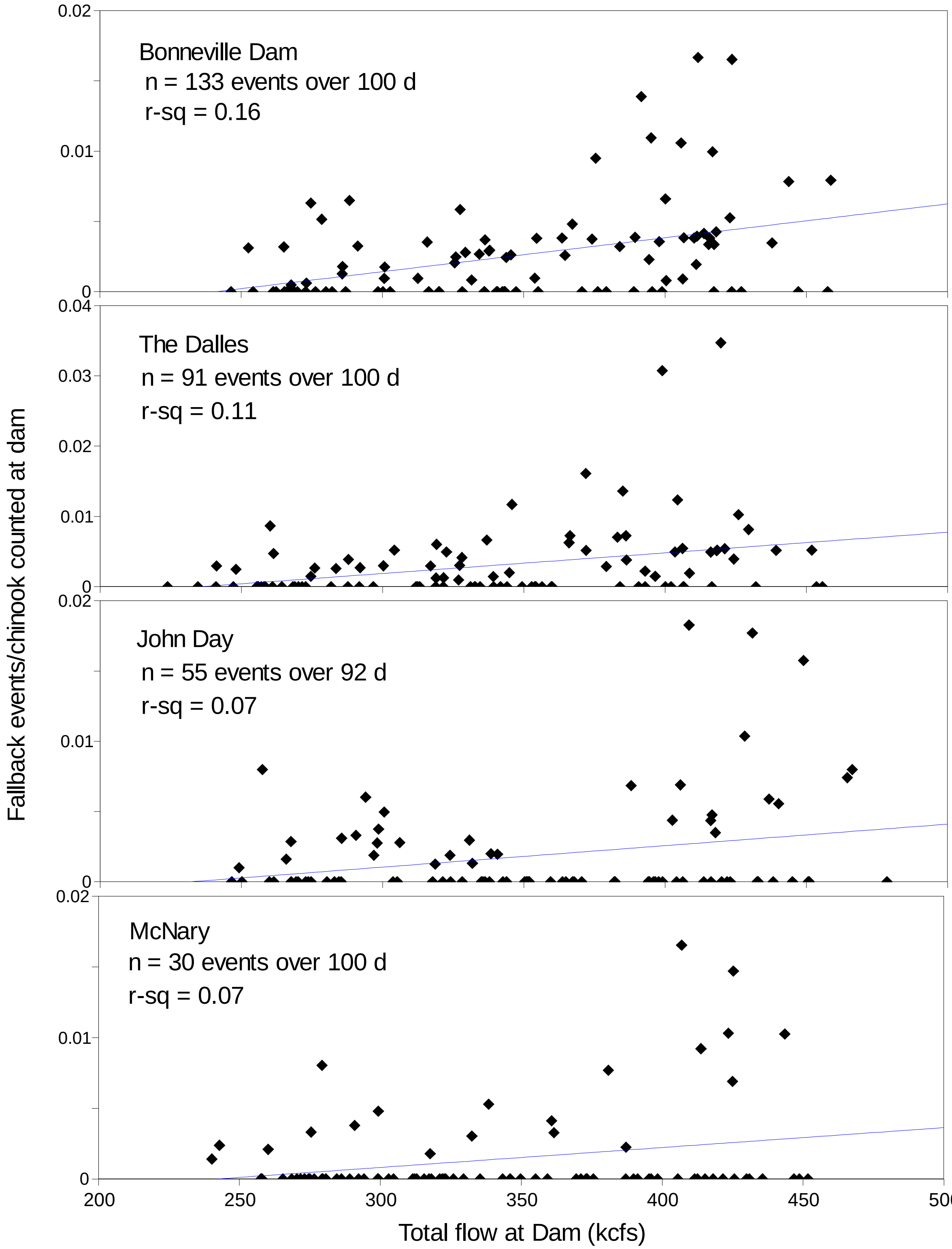

Figure 32. Ratio (fb_n/c_n) of chinook salmon with transmitters that fell back (fb_n) to the number counted (c_n) at Bonneville, The Dalles, John Day and McNary dams versus mean daily flow.

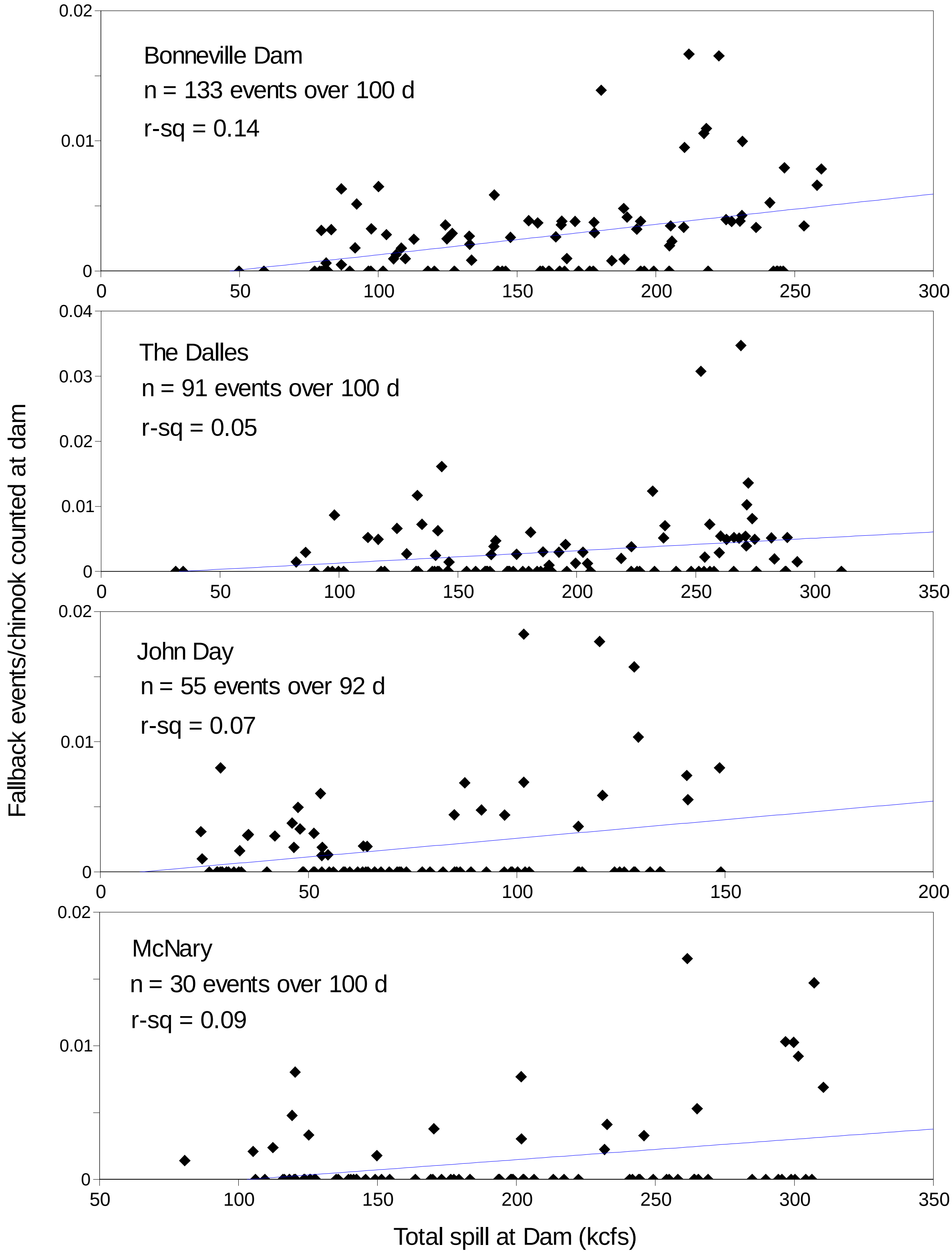

Figure 33. Ratio (fbn/c_n) of chinook salmon with transmitters that fell back (fb_n) over the number counted (c_n) at Bonneville, The Dalles, John Day and McNary dams versus mean daily spill.

individual fallback events, we used a number of techniques to examine the relationship between fallback and environmental conditions. At Bonneville, The Dalles, and John Day dams we used moving averages and blocking of data based on days and numbers of fish, as well as standard linear and logistic regressions and multiple regression models. Refer to Bjornn et al. 2000b; 2000c; and 2000d for detailed reports on fallbacks at Bonneville, The Dalles, and John Day dams.

Because relatively few chinook salmon fell back within 24 h at dams upriver from John Day Dam, we did not attempt to analyze the effects of environmental conditions on fallbacks at those dams for 1996.

Effect of Fallbacks on Passage Time

Chinook salmon that fell back at any dam in 1996 had significantly longer passage times past multiple dams than fish that did not fall back. Median passage times from release after tagging to the most upriver dam passed were longest for chinook salmon that fell back more than once, and fish that fell back once had longer passage times than fish that did not fall back (Figure 34.) It is important to note that chinook salmon that fell back but did not survive to reascend the dams were not included in our analyses. While delayed passage may impact survival, direct and indirect mortality due to fallback was not addressed in this section.

Median passage times, from release to the time that chinook salmon last exited from the top of a ladder at a dam, were 2.6 to 4.4 days longer for fish that fell back once versus those that did not fall back (Figure 34). Chinook salmon that fell back more than one time had median passage times 7.1 to 14.8 days longer than fish that did not fall back, with the exception of Priest Rapids Dam, where two fish that fell back multiple times had median passage time more than 31 d longer than fish that did not fall back. When all fish that fell back were combined, one or more fallbacks at any location added 4.1 to 6.7 d to median passage times from release to passage at an upstream dam (Figure 34).

Median passage times from release to the top of Bonneville, The Dalles, John Day, McNary and Ice Harbor dams were significantly ($P < 0.001$) longer for fish that fell back one or more times than for those that did not fall back. Median passage times were also significantly ($P < 0.05$) longer for fish that fell back one or more times for those that passed Lower Granite and Priest Rapids dams. Although there were problems with normalcy because passage times were right-skewed, mean passage times from release to the top of dams were also significantly longer ($P < 0.001$) for chinook salmon that fell back one or more times then passed Bonneville, The Dalles, John Day, McNary and Ice Harbor dams than for those that did not fall back. Mean passage times were also significantly longer ($P < 0.02$) for fish that fell back one or more times at any location than for fish that did not fall back for those that passed Lower Granite or Priest Rapids dams.

We also tested whether a single (not more than one) fallback at any location significantly affected passage time from release to the tops of dams. For chinook salmon that passed Bonneville and The Dalles dams, median passage times were significantly longer ($P < 0.001$) for fish that

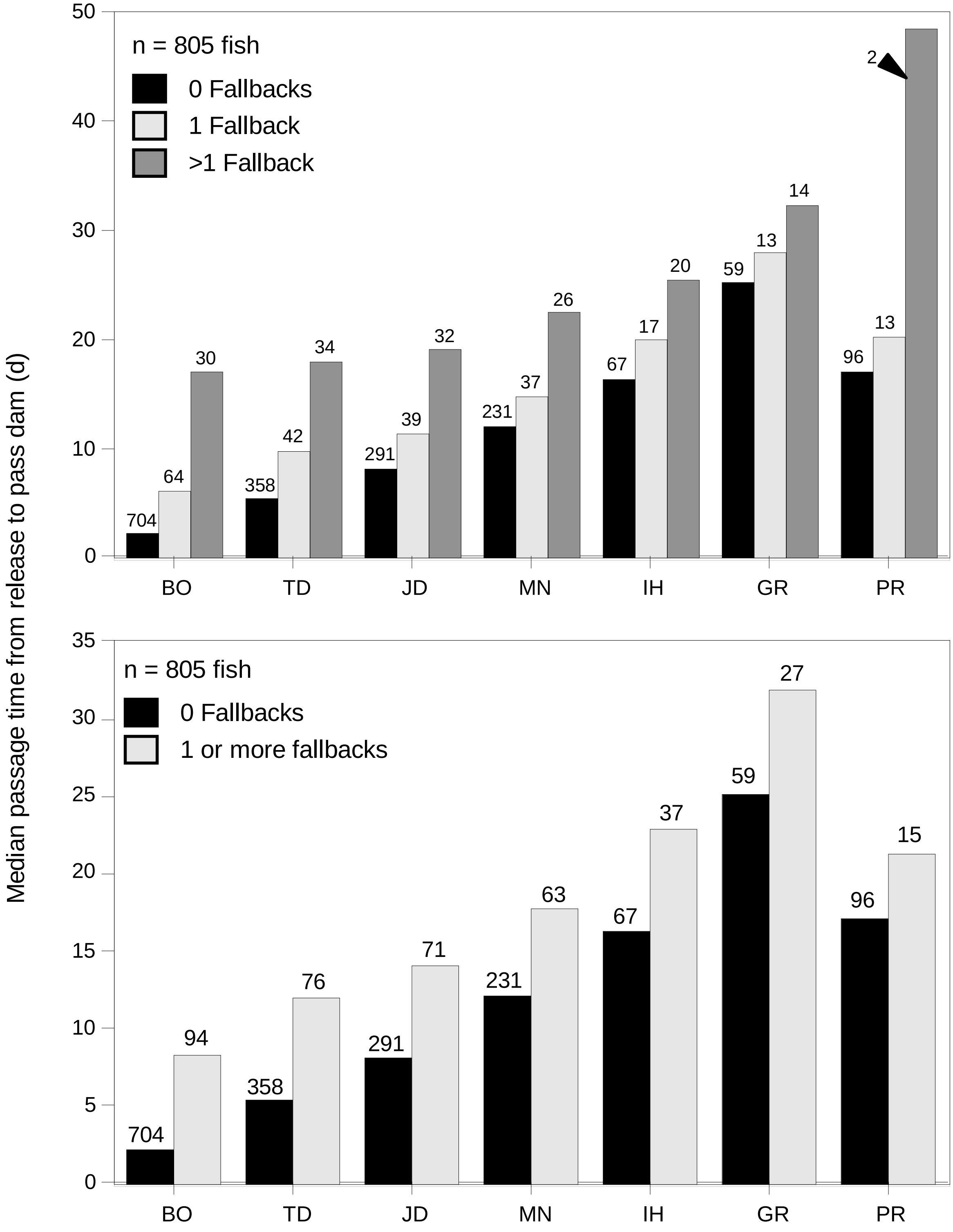

Figure 34. Median passage times from release after tagging to pass dams for chinook salmon that did not fall back, or fell back once or more than once (upper graph), or did not fallback versus fell back one or more times at any dam in 1996 (lower graph). Numbers above the bars are number of fish in each category.

fell back once at any location than for fish that did not fall back, and the same was true for fish that fell back once at any location and passed John Day Dam ($P < 0.01$), and McNary or Ice Harbor dams ($P < 0.05$). One fallback event at any location did not significantly affect passage times for chinook salmon from release past Lower Granite or Priest Rapids dams.

At the four lower Columbia River dams, chinook salmon with transmitters that fell back more than one time at any location had significantly longer ($P < 0.001$) mean and median passage times from release to passage at the dams than fish that fell back only one time. Fish that had multiple fallbacks did not have significantly longer ($P > 0.05$) passage times from release to past Ice Harbor, Lower Granite, or Priest Rapids dams than fish that fell back only once.

As reported in sections on passage time, summer chinook salmon migrated through the main stem Columbia and Snake rivers more rapidly than spring chinook salmon. We were concerned that the different migration rates could skew fallback analyses. In particular, a comparison that included spring chinook salmon that fell back and summer chinook salmon that did not fall back could exaggerate the effects of fallback events on passage time. When we analyzed spring and summer chinook salmon separately, we found that fallbacks caused delays in migration for both spring and summer fish, but particularly for spring chinook salmon (Figure 35). For 664 spring chinook salmon, one or more fallback events at any dam added 5 to 8.9 days to the median migration time from release to the last passage of an individual dam. The largest differences in median passage time for spring chinook salmon were for fish that fell back before their last passage at The Dalles Dam (8.9 d longer than fish that did not fall back), and for fish that fell back before their last passage at John Day Dam (8.5 d longer) (Figure 35). Forty-four spring chinook salmon that passed Lower Granite Dam without falling back at any location had a median passage time of 28.1 d versus 33.1 d for 23 fish that passed Lower Granite Dam but fell back one or more times at any location. The 5-d difference in median times for fish that passed Lower Granite Dam was smaller than for fish that passed the other dams.

Median and mean passage times for spring chinook salmon that fell back one or more times at any location were significantly longer ($P < 0.001$) from release to Bonneville, The Dalles, John Day, McNary and Ice Harbor dams. Spring chinook salmon that fell back also had significantly longer passage times to Lower Granite and Priest Rapids dams, but at a lower significance level ($P < 0.05$).

Smaller sample sizes for summer chinook salmon made comparisons more difficult than for spring chinook salmon, but in general a fallback at any dam added from one to four days to the median migration time from release to the last passage of an individual dam for the summer migrants (Figure 35). Median passage times for summer chinook salmon that fell back were significantly longer ($P < 0.01$) than for fish that did not fall back that passed Bonneville and The Dalles dams. Differences in mean and median travel times for fallback versus non fallback summer chinook salmon from release to passage of dams upriver from The Dalles were not significant at $P<0.05$, perhaps in part because sample sizes were small.

Passage time distributions for fish that did or did not fall back during their migration showed that fallbacks delayed most fish, and that significant differences we report above were not due to a few fish with greatly delayed passage. For chinook salmon that passed McNary Dam, mean passage from release to the top of McNary Dam for fish that did not fall back was 13.6 d (median 12.1 d) compared to mean passage of 19.9 d for fish that fell back (median 17.7 d) (Figure 36). Chinook salmon that passed Ice Harbor Dam but did not fall back had mean passage of 17.2 d (median 16.3 d) from release, while those that fell back had mean passage of 24.8 d (median 22.9 d) (Figure 37). Mean passage for fish that passed Lower Granite Dam and did not fall back was 27.6 d (median 25.2 d) and mean passage for those that fell back was 33.7 d (median 31.8 d) (Figure 38).

Median passage times from tailrace to top-of-ladder sites for chinook salmon that fell back and reascended at Bonneville, The Dalles, and John Day dams were similar for first and second passages of dams, and were less than 24 h at Bonneville and The Dalles dams and about 30 h at John Day Dam (Figure 39). Median passage times for fish that did not fall back were similar to those for fish that fell back. Median times between first and second passages for fish that fell back and reascended were about 200 h (~ 8 d) at The Dalles and John Day dams and 135 h at Bonneville Dam. Time fish spent between passages was primarily in reservoirs or passing upstream dams prior to falling back. We also calculated first and second passage times from the first recorded approach to the Bonneville Dam fishway to the top-of-ladder sites for 102 chinook salmon that fell back and reascended. Median first passage time for the 102 fish was 14.3 h and median second passage time was 12.1 h, a difference that was not significant ($P > 0.10$). We did not monitor The Dalles or John Day dams with a full array of antennas in 1996.

In regressions of cumulative fallbacks versus passage time past multiple dams there were positive slopes to the regression lines and fallbacks accounted for 15% to 27% of the variation in passage time for chinook salmon with transmitters from release to McNary, Ice Harbor, Lower Granite and Priest Rapids dams (Figure 40).

Reascension Over Dams and Final Distribution after Fallbacks

At least 123 (66%) of the 185 chinook salmon with transmitters that fell back one or more times in 1996 reascended all dams at which they fell back, based on fixed receiver, mobile-tracking and recapture records. Of the remaining 62 fish, some reascended dams after falling back, but did not reascend all dams at which they fell back. About 58% of the chinook salmon that did not reascend the most upriver dam they passed were subsequently recorded in tributaries downstream from the fallback location and potentially reached spawning sites.

Fallbacks by fish that subsequently entered tributaries downstream from the dam where they fell back were likely caused by fish migrating upstream past their natal stream and then having to return downstream. But, they may also have been fish that were destined for other streams and permanently strayed

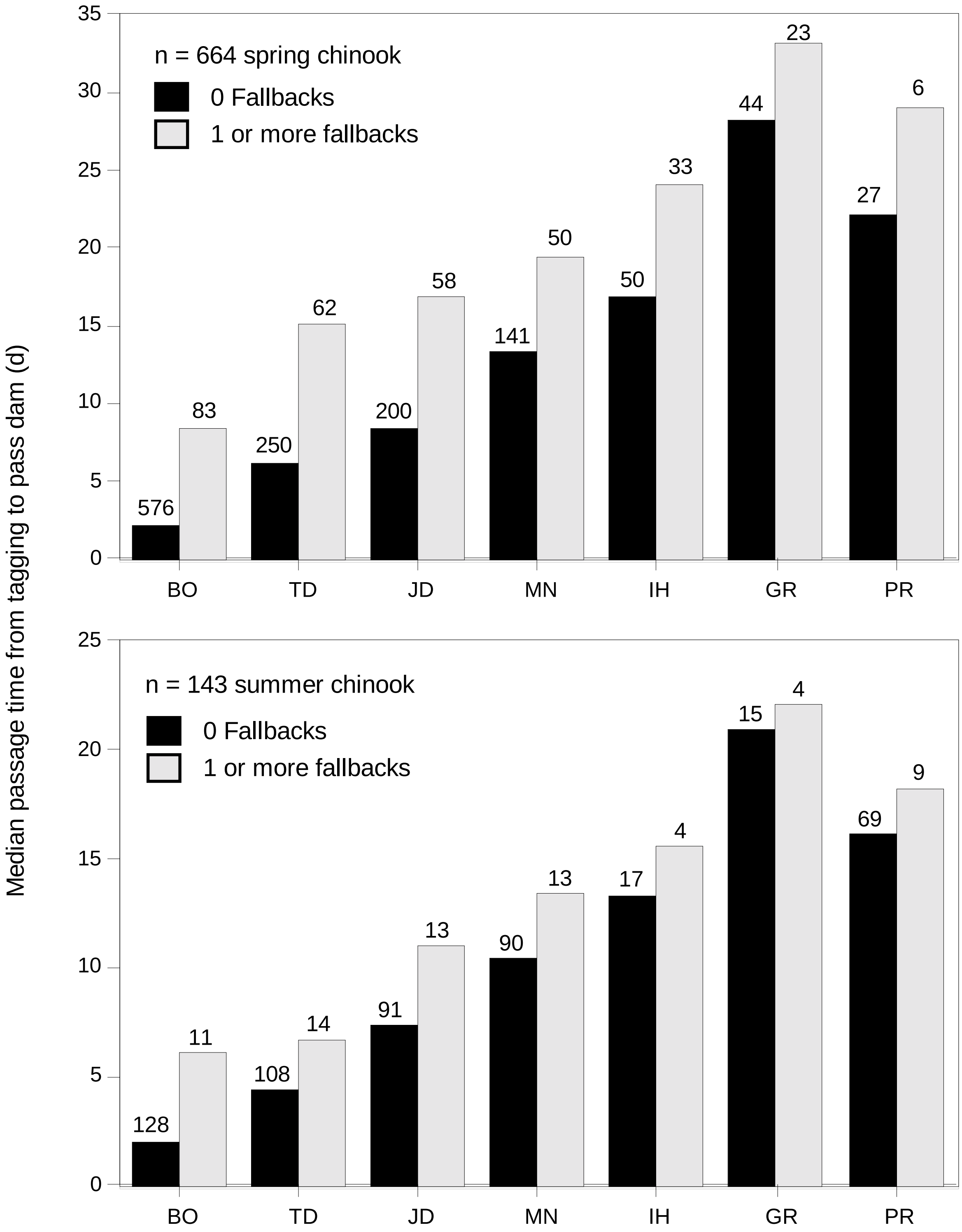

Figure 35. Median passage times from release after tagging to the last exit from the top of ladders at each dam for spring (upper graph) and summer chinook salmon that did not fall back, or fell back one or more times at any dam in 1996. Numbers above the bars are number of fish in each category.

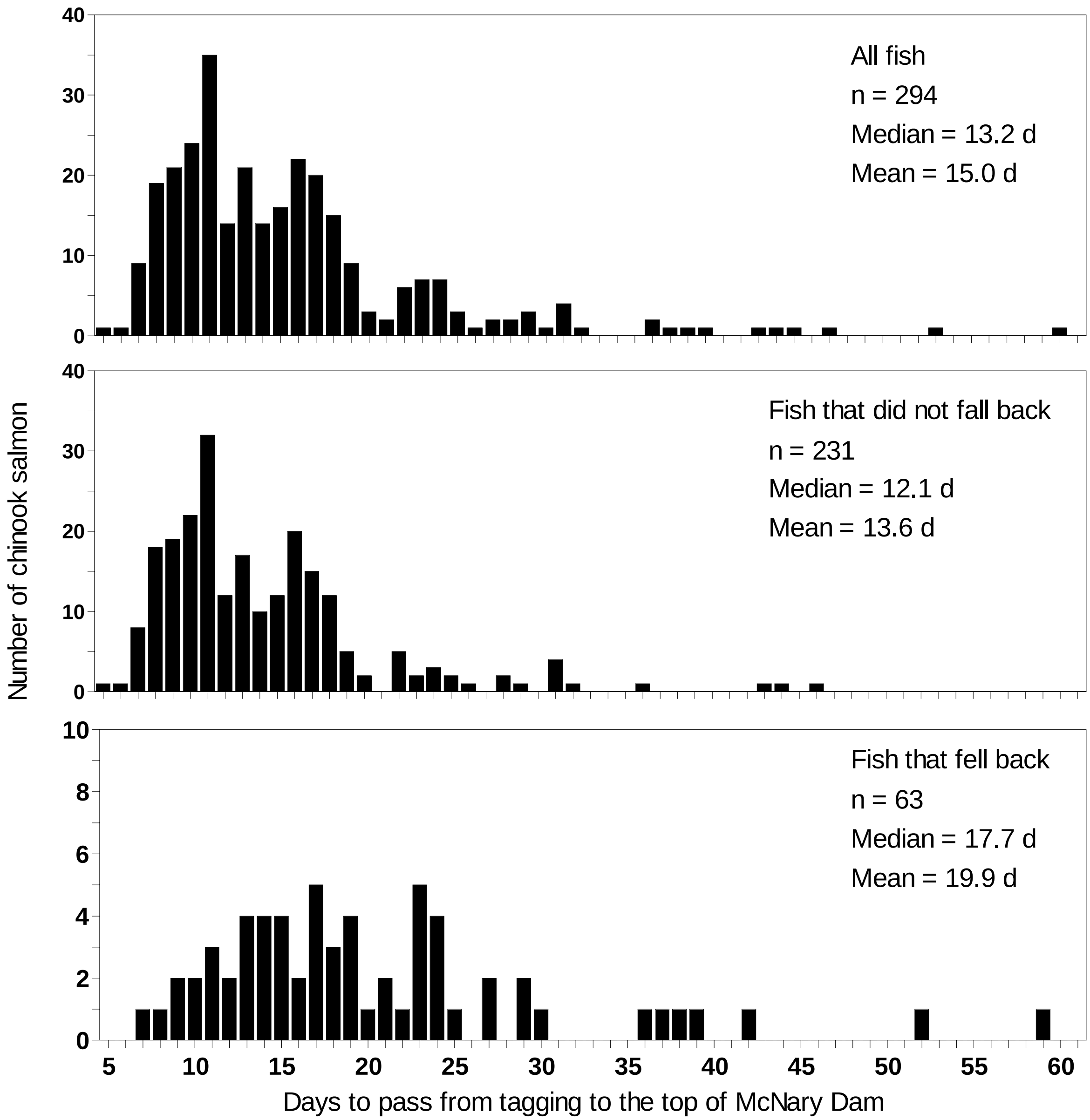

Figure 36. Days to pass from release to the top of McNary Dam by all chinook salmon, and by fish that did or did not fall back at any location before passing McNary Dam for the last time in 1996.

into the tributary where they were last located. Most (~70%) of the fish only migrated past the dam immediately upriver from the tributary they eventually entered, but some (~30%) passed multiple dams upriver from the tributary they subsequently entered (Table 26).

Of the 12 chinook salmon that fell back at Bonneville Dam and did not reascend, 42% entered downstream tributaries (Table 26). Of 30 fish that fell back at The Dalles Dam and did not reascend, 60% entered downstream tributaries. Nine of 19 (47%) fish that fell back at John Day Dam, and 12 of 18 (66%) fish that fell back at McNary Dam and did not

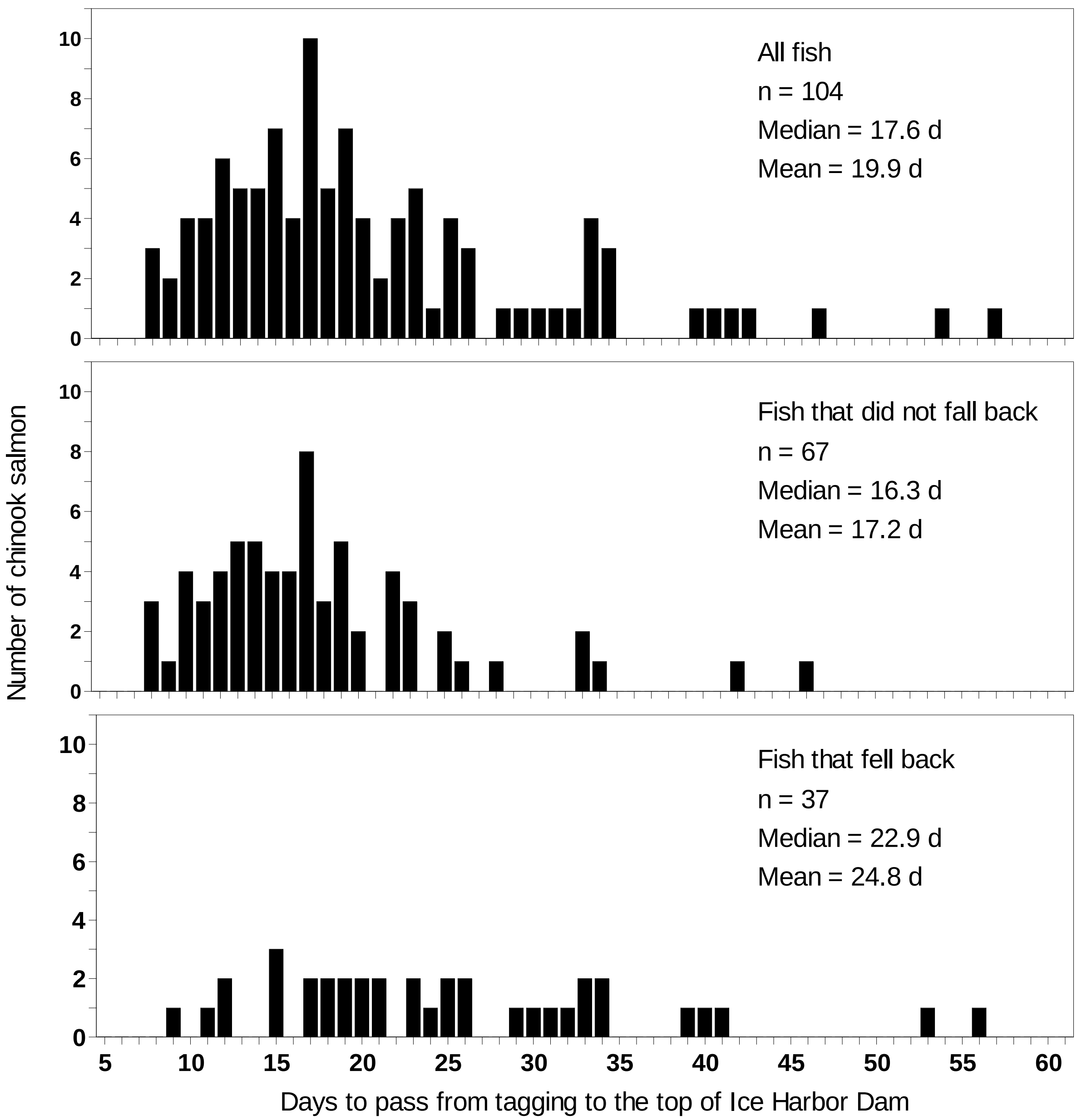

Figure 37. Days to pass from release to the top of Ice Harbor Dam by all chinook salmon, and by fish that did or did not fall back at any location before passing Ice Harbor Dam for the last time in 1996.

reascend entered downstream tributaries. The 2 fish that fell back at Ice Harbor and did not reascend both entered the Umatilla River (Table 26).

Because we did less mobile tracking in Snake River tributaries in 1996 than in previous years, chinook salmon that were recorded at receivers at the mouth of the Clearwater River or in the Snake River near Asotin, WA were classified as having reached tributary destinations. This differed from previous years, when Snake River tributaries with spawning areas were monitored more extensively and survival to known spawning grounds could be more

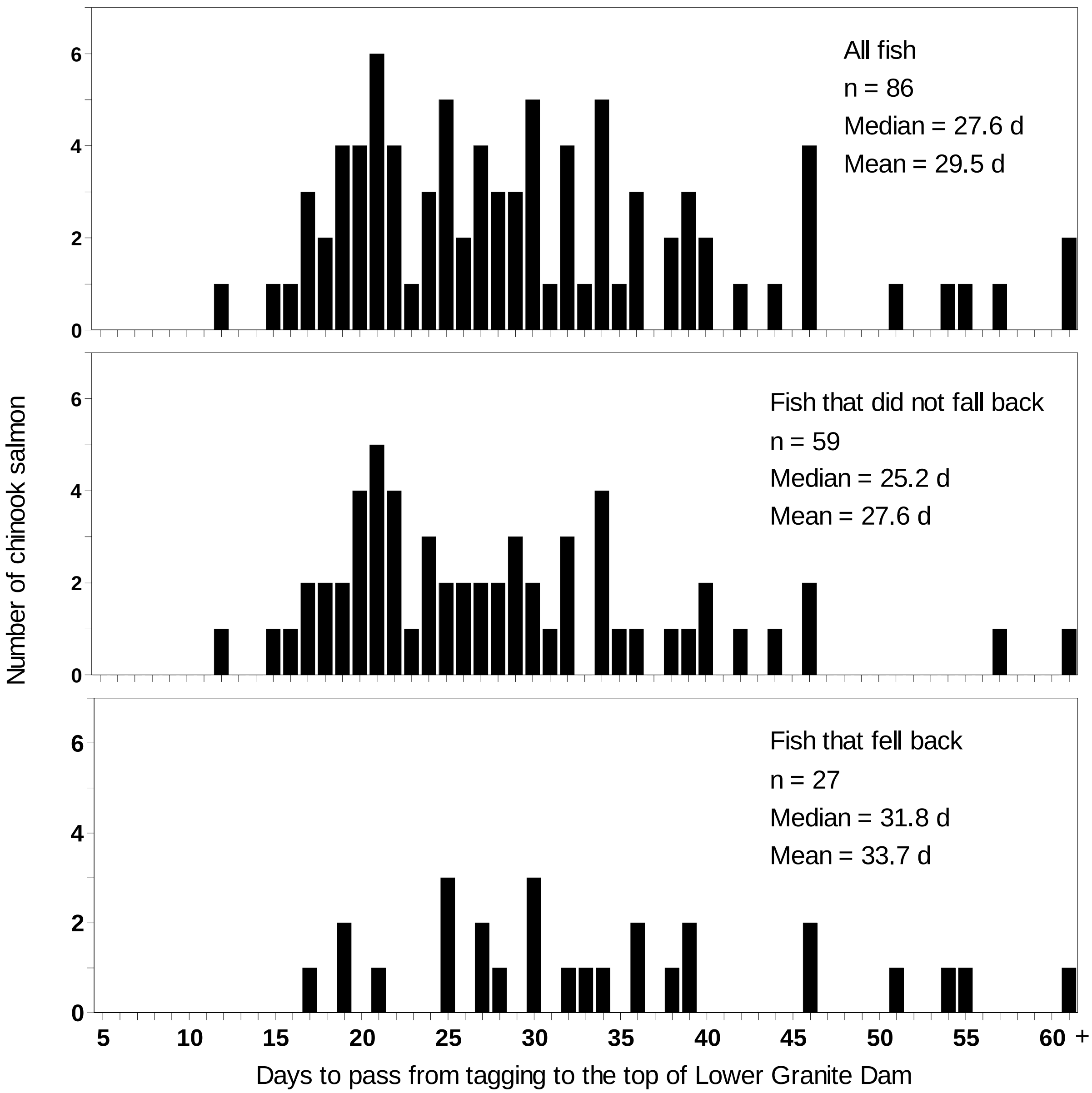

Figure 38. Days to pass from release to the top of Lower Granite Dam by all chinook salmon, and by fish that did or did not fall back at any location before passing Lower Granite Dam for the last time in 1996.

accurately assessed. There were no fixed-site receivers and limited mobile tracking upriver from Priest Rapids Dam in 1996, but there were records from recaptures at weirs, hatcheries and in fisheries. Because of the limited upriver coverage, we treated chinook salmon that passed Priest Rapids Dam as a special case; as noted below, in some instances fish that passed Priest Rapids were considered to have reached tributary destinations.

An estimated 74% of all radio-tagged chinook salmon that fell back at any location eventually reached tributary sites,

Table 26. Number of chinook salmon that did not reascend dams where they fell back, and did or did not enter downstream tributaries after falling back in 1996.

	Fell back and did not reascend	Did not enter tributary	Entered downstream tributary	Final distribution (river entered)
Fish that fell back and did not reascend at one or more dams				
	62	26	36	Cowlitz (2), Santiam (1), Sandy (3), Wind (5), Little White Salmon (3), White Salmon (1), Hood (1), Klickitat (5), Deschutes (5), John Day (2), Umatilla (8)
Bonneville	12	7	5	Cowlitz (1), Santiam (1), Sandy (3)
The Dalles	30	12	18	Klickitat (5), Little White Salmon (3), Wind (4), Santiam (1), Cowlitz (1), Sandy (1), White Salmon (2), Hood (1)
John Day	19	6	9	Deschutes (5), Sandy (1), Cowlitz (1), White Salmon (1), Klickitat (1)
McNary	18	6	12	John Day (2), Deschutes (1), White Salmon (1), Umatilla (8)
Ice Harbor	2	0	2	Umatilla (2)

Table 27. Survival to major tributaries[a] by 808 chinook salmon with transmitters that passed Bonneville Dam in 1996 and either did or did not fall back at Bonneville Dam and did or did not fall back at any dam during their migration.

	Did not fall back		Fell back one or more times	
	Number	Percent	Number	Percent
Fallbacks occurred at Bonneville Dam				
Survived	541	77.7	80	71.4
Did not survive	144	20.7	31	27.7
Survival unknown[b]	11	1.6	1	0.9
Total	(696)		(112)	
Fallbacks occurred at any monitored dam during migration				
Survived	484	77.7	137	74.1
Did not survive	130	20.9	45	24.3
Survival unknown[b]	9	1.4	3	1.6
Total	(623)		(185)	

[a] Due to limited mobile tracking of tributaries in 1996, survival to ‘major tributaries’ included all fish that were recorded in tributaries with fixed receivers at their mouths, including the Clearwater River, the Snake River near Asotin, WA, and the top of Priest Rapids Dam. Only fish that remained in tributaries long enough to potentially spawn were considered to have survived.

[b] Fish that were recaptured at Lower Granite trap and released without transmitters

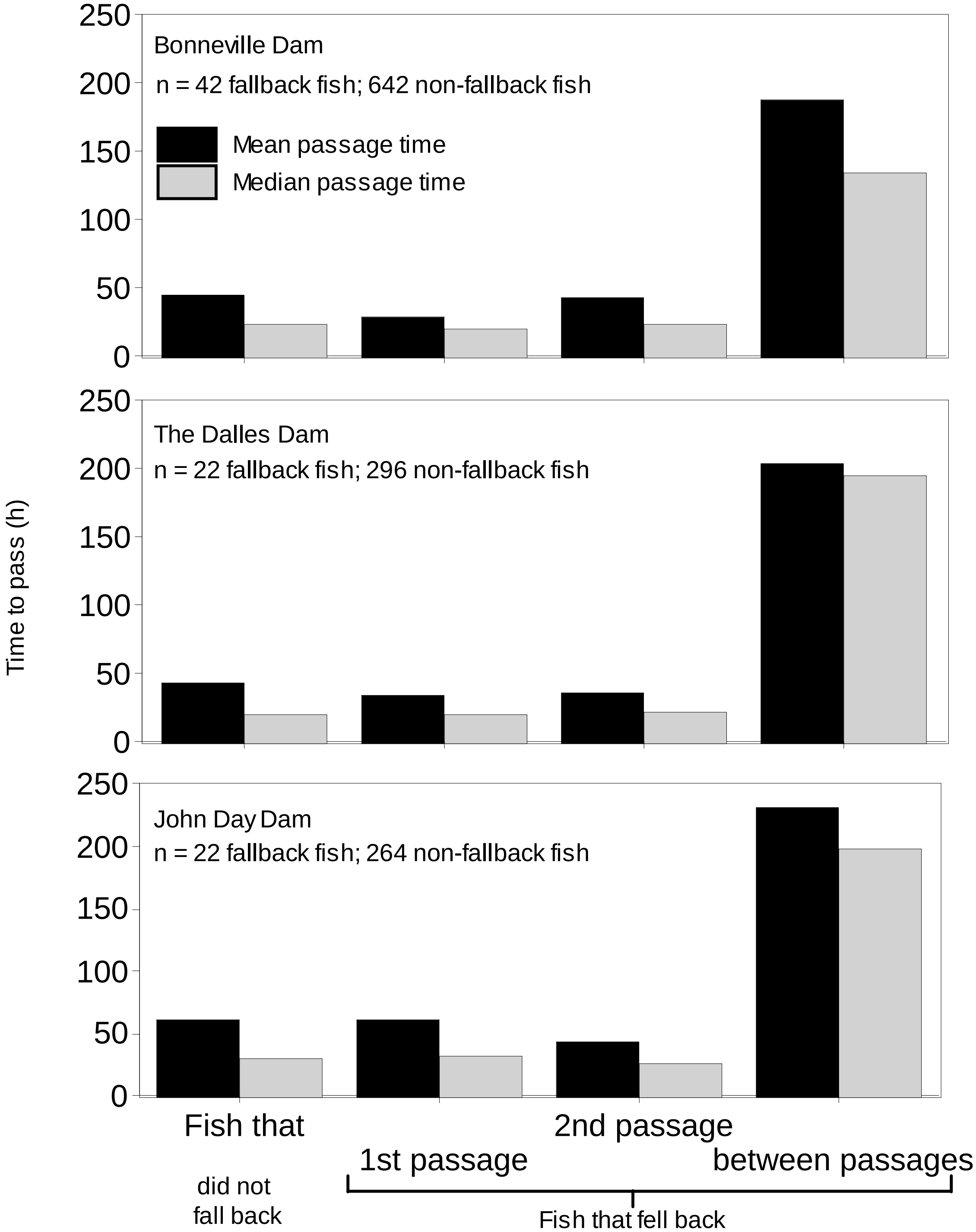

Figure 39. Mean and median passage times for spring and summer chinook salmon that did or did not fall back to pass from tailrace to top-of-ladder sites at Bonneville, The Dalles, and John Day dams in 1996. First and second passage times and the time between first and second passages are included for fish that fell back.

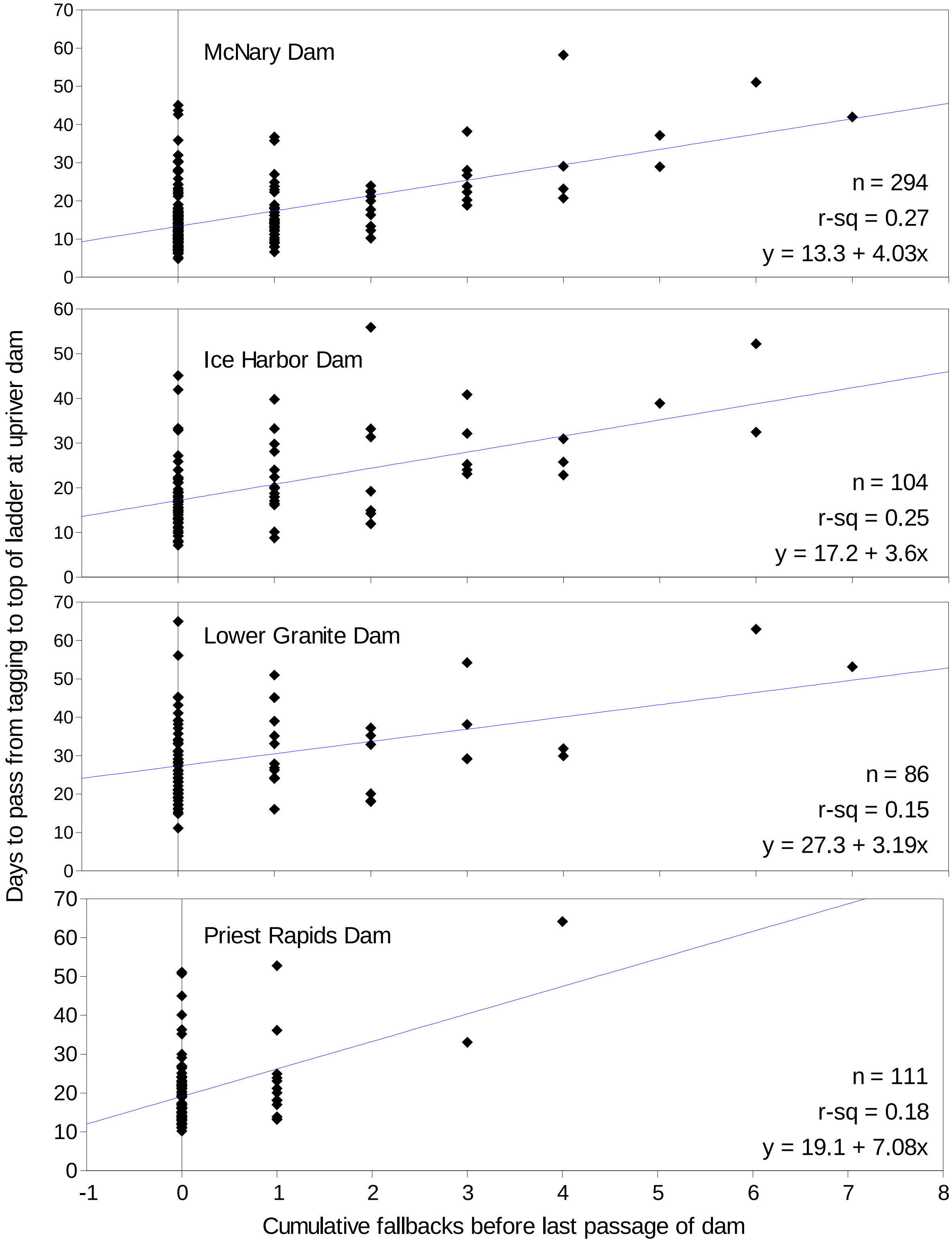

Figure 40. Cumulative fallback events by chinook salmon at downstream dams versus time to pass from release after tagging to top-of-ladder receivers at McNary, Ice Harbor, Lower Granite and Priest Rapids dams in 1996.

either upriver or downstream from the fallback location (Table 27). Survival of the fallback fish was based primarily on telemetry or recapture records that indicated a fish had entered and remained in a tributary long enough to spawn or be recaptured. The survival rate also included fish transported from the Lower Granite adult trap to hatcheries, in the Snake River near Asotin, at the mouth of the Clearwater River, in the lower Deschutes River, at the top of Priest Rapids Dam, and at Wells Dam. It is likely that some chinook salmon with last records in tributaries did not spawn or were recaptured before spawning occurred. It was also possible that a few fish that were last recorded at dams or at main stem sites and classified as non survivors, eventually survived to reach tributaries or spawning areas undetected (most likely if they lost their transmitter). With those qualifications, survival to tributaries ranged from 66% to 74% for fish that fell back at one or more of the lower Columbia River dams and 100% for fish that fell back at Ice Harbor Dam (Table 28). All six chinook salmon that fell back at Priest Rapids Dam reascended and the fish that fell back at Lower Granite Dam reascended and entered a Clearwater River tributary. When passage of Priest Rapids Dam was treated as survival to a tributary, the overall survival rate for chinook salmon that fell back was 74.1% (Table 27). By comparison, of all 838 chinook salmon that retained transmitters in 1996 (including fallback fish), 66% returned to tributary sites and another 8% returned to the top of Priest Rapids Dam for an overall survival rate of 74% (Table 30). A portion of the 838 fish entered tributaries downstream from Bonneville Dam and did not have an opportunity to fall back.

Chinook salmon that passed dams and did not fall back survived at higher rates than fish that passed dams and fell back. For chinook salmon that did or did not fallback at Bonneville Dam, survival of 696 non-fallback fish was 77.7% versus 71.4% for 112 fish that fell back (Table 27). The difference was not significant at $P < 0.10$. When we classified as survived fish that were recaptured at the Lower Granite trap and released without transmitters, salmon that did not fall back at Bonneville Dam survived at significantly ($P < 0.10$) higher rates than fish that did fall back at Bonneville Dam (79.3% versus 72.3%). Survival for the 623 fish that did not fall back at any monitored dam was 77.7% versus 74.1% for the 185 fish that fell back at a dam; the difference was not significant at $P < 0.10$. The difference was also not significant ($P < 0.10$) when we classified fish recaptured without transmitters at Lower Granite trap as survived (79.1% versus 75.7%).

Of 112 fish that fell back at Bonneville Dam, 5 (4%) were later recorded in tributaries downstream from the dam, 25 (22%) in tributaries between Bonneville and The Dalles dams, 16 (14%) in the Deschutes and John Day rivers, 1 in the Umatilla River, 21 (19%) in the Snake River upriver from Lower Granite Dam or at the Lower Granite Trap and 6 (5%) in Columbia River tributaries upriver from McNary Dam (Table 28). Last records for the 38 chinook salmon that fell back at Bonneville Dam and did not reach tributary sites were mostly (67%) at or downstream from Bonneville Dam, in the Bonneville pool or at The Dalles Dam. Six fish (5%) were last recorded at the top of Priest Rapids Dam.

Of 66 chinook salmon that fell back at The Dalles Dam, 3 (5%) were later

Table 28. Final location of chinook salmon with transmitters that fell back (FB) over monitored dams in 1996 and percent that reached tributaries, based on last records for fish and/or evidence that fish reached spawning areas before returning to main stem sites. (Note: totals do not add up because some fish fell back at more than one dam.)

	All fish	FB at BON	FB at TD	FB at JD	FB at McN	FB at IH
Number of FB fish	185	112	66	47	27	9
Final location						
Cowlitz River	2	1	1	1		
Santiam River	1	1	1			
Sandy River	3	3	1	1		
Wind River	13	10	4			
Little White Salmon R.	15	12	3			
White Salmon River	2	1	2	1	1	
Hood River	1		1			
Klickitat River	6	2	5	1		
Deschutes River	13	8	5	5	1	
John Day River	11	8	2	2	2	
Umatilla River	9	1	3	2	8	2
Yakima River	5	3		1	1	
Near Ringold Trap	2				2	
Icicle River	2	2				
Similkameen River	1	1				
Tucannon River	4		2	1	1	3
Clearwater River	9	6	6	4	3	2
Snake R. at Asotin	9	7	3	2	1	
Grande Ronde River	1					1
Salmon River	9	3	3	5		1
Number recaptured at Lower Granite Trap and transported to a Hatchery	6	4	4	4		
Number recaptured at Lower Granite Trap without functioning transmitter	3	1	1	3		
Number recaptured at Wells Dam	3					
Number at tributary sites, including Lower Granite Trap and Wells Dam	130	74	46	33	20	9
Number with last record at a dam or main stem site	53	38	20	14	7	0
Number with last record at top of Priest Rapids Dam	11	6	4	2	1	
Percent with records at tributaries or hatcheries	71	66	70	70	74	100
Percent with records at tributaries, hatcheries or the top of Priest Rapids Dam	76	71	76	74	78	100

[a] Of 6 fish that fell back at Priest Rapids Dam, 3 were recorded at Wells Dam and three reascended Priest Rapids Dam. The one fish that fell back at Lower Granite Dam returned to a Clearwater River tributary.

recorded in tributaries downstream from Bonneville Dam, 15 (23%) in tributaries between Bonneville and The Dalles dams,7 (11%) in the Deschutes or John Day rivers, 17 (26%) in Snake River tributaries upriver from Lower Granite Dam or in the Lower Granite Trap, 3 (5%) in the Umatilla River and 2 (3%) in the Tucannon River (Table 28). Nineteen fish (29%) fell back at The Dalles Dam and were not recorded in tributaries, of which more than 60% were last recorded in the Bonneville pool or at The Dalles Dam.

Of 47 chinook salmon that fell back at John Day Dam, two (4%) were last recorded in tributaries downstream from Bonneville Dam, 7 (15%) were recorded in the Deschutes or John Day rivers, 18 (38%) in tributaries upriver from Lower Granite Dam or in the Lower Granite Trap, and six among the Little White Salmon, Klickitat, Umatilla, Yakima and Tucannon rivers (Table 28). Seven of the 14 fish that fell back at John Day Dam and were not recorded in tributary sites were last recorded in reservoirs downstream from John Day and The Dalles dams or at those dams.

Of 27 chinook salmon that fell back at McNary Dam, 12 (44%) were recorded in tributaries downstream from McNary Dam, including 8 (30%) in the Umatilla River; 1 was in the Columbia River near Ringold Trap, 1 in the Tucannon River, 3 (11%) in the Clearwater River and 1 in the Snake River near Asotin, WA (Table 28). Of the 8 not recorded in tributaries, 6 were recorded at dams or main stem sites downstream from McNary Dam and 1 was recorded at the top of Priest Rapids Dam and 1 in the Hanford Reach. Nine fish fell back at Ice Harbor Dam and all were subsequently recorded in tributary sites: 2 in the Umatilla, 3 in the Tucannon, 2 in the Clearwater and 1 each in the Grande Ronde and Salmon rivers (Table 28). Chinook salmon that fell back at Lower Granite and Priest Rapids dams all reascended and all but one reached tributary or hatchery sites (see footnote to Table 28).

Timing of Migration Past Dams and into Tributaries

Adult spring and summer chinook salmon with transmitters started migrating into tributaries in mid-April and continued through August, but most fish entered tributaries in May, June and early July (Figures 41 and 42). In general, fish entered lower Columbia River tributaries early in the migration and progressively later into mid-Columbia and Snake River tributaries. Because there were no fixed receivers at tributaries upriver from Priest Rapids Dam, arrival at the dam was used as a surrogate for arrival at mid-Columbia tributaries.

At most sites, arrivals were spread over six to eight weeks, with approximately symmetrical distributions around median arrival dates. Median arrivals for lower Columbia River tributaries were 15 May at the Wind, 11 May at the Little White Salmon, 23 May at the White Salmon, 1 June at the Klickitat, 15 May at the Deschutes and 8 May at the John Day rivers. There were no fixed receivers in place at the Umatilla or Tucannon rivers during the 1996 chinook salmon migration. Median arrival dates were 27 May at the Yakima River and 30 June at Priest Rapids Dam, with a distinct split between summer and spring chinook salmon arrivals at Priest Rapids Dam. Median arrival dates at the dam were 23 May for spring fish and 4 July for summer fish. In the Snake River drainage, median arrival dates were 25 May at Ice Harbor Dam, 3 June at Lower Granite

Dam, 15 June at the Snake River site near Asotin, WA and 12 June at the Clearwater River (Figures 41 and 42).

Chinook salmon migrated into tributaries throughout the day and nighttime hours, with slightly fewer fish first passing receivers during midday hours (Figure 43). The Snake River site near Asotin, WA was an exception, as more fish passed the receiver there during daylight hours. The Asotin site was also unique in that it was not a tributary mouth per se, but rather recorded fish after they passed out of the Lower Granite pool into a free-flowing section of the Snake River. Another exception was at the Klickitat River, where no chinook salmon were first recorded between midnight and approximately 0500 hours.

Length frequencies of chinook salmon with transmitters differed among major tributaries and at Priest Rapids Dam, primarily because of the distribution of the larger summer chinook salmon that were not present in all tributaries (Figure 44; also see Figure 6 for lengths of all chinook salmon tagged in 1996). We included fish at each site based on the location of their last known record. The largest fish for any tributary were the six summer chinook salmon last recorded in the Imnaha River, with a median fork length when tagged of 81 cm. Median fork length for 115 spring and summer chinook salmon last recorded at or upriver from Priest Rapids Dam was 79.5 cm; 75 were summer chinook salmon with median length of 85.5 cm and 40 were spring chinook salmon with median length of 76.8 cm when they were tagged. Chinook salmon that returned to the Tucannon, Yakima and John Day rivers were almost all spring fish with median fork lengths between 71 and 72 cm, the smallest medians among tributary returns (Figure 45).

Tag Dates for Specific Stocks of Chinook Salmon with Transmitters

Identifying distinct adult salmon and steelhead stocks at lower Columbia River dams during annual runs has been a management challenge. In 1996, we used tag dates and final distribution records for radio-tagged chinook salmon to identify when specific upriver stocks passed Bonneville Dam. Although sample sizes of radio-tagged fish were low for some tributaries, we did find that some stocks predominantly passed Bonneville Dam in either early or late portions of the spring and summer chinook salmon runs; other stocks, like those bound for the Snake and Deschutes rivers, were distributed throughout the migration season.

Chinook salmon that returned to the Wind and Little White Salmon rivers were outfitted with transmitters at Bonneville Dam mostly from mid-April to the end of May, with median tag dates in the first week of May (Figure 46). The small number of fish that returned to the White Salmon and Klickitat rivers were outfitted with transmitters from late April through mid-June and had median tag dates of 15-May and 24-May. Chinook salmon that returned to the Deschutes River were outfitted with transmitters throughout the migration season, from the onset of tagging in early April, through the end of June. The median passage date for Deschutes' returns was 9-May (Figure 46).

Most returns to the John Day and Umatilla rivers were outfitted with transmitters in April and early May, with median tag dates in the last week of April (Figure 47). Returns to the Yakima River

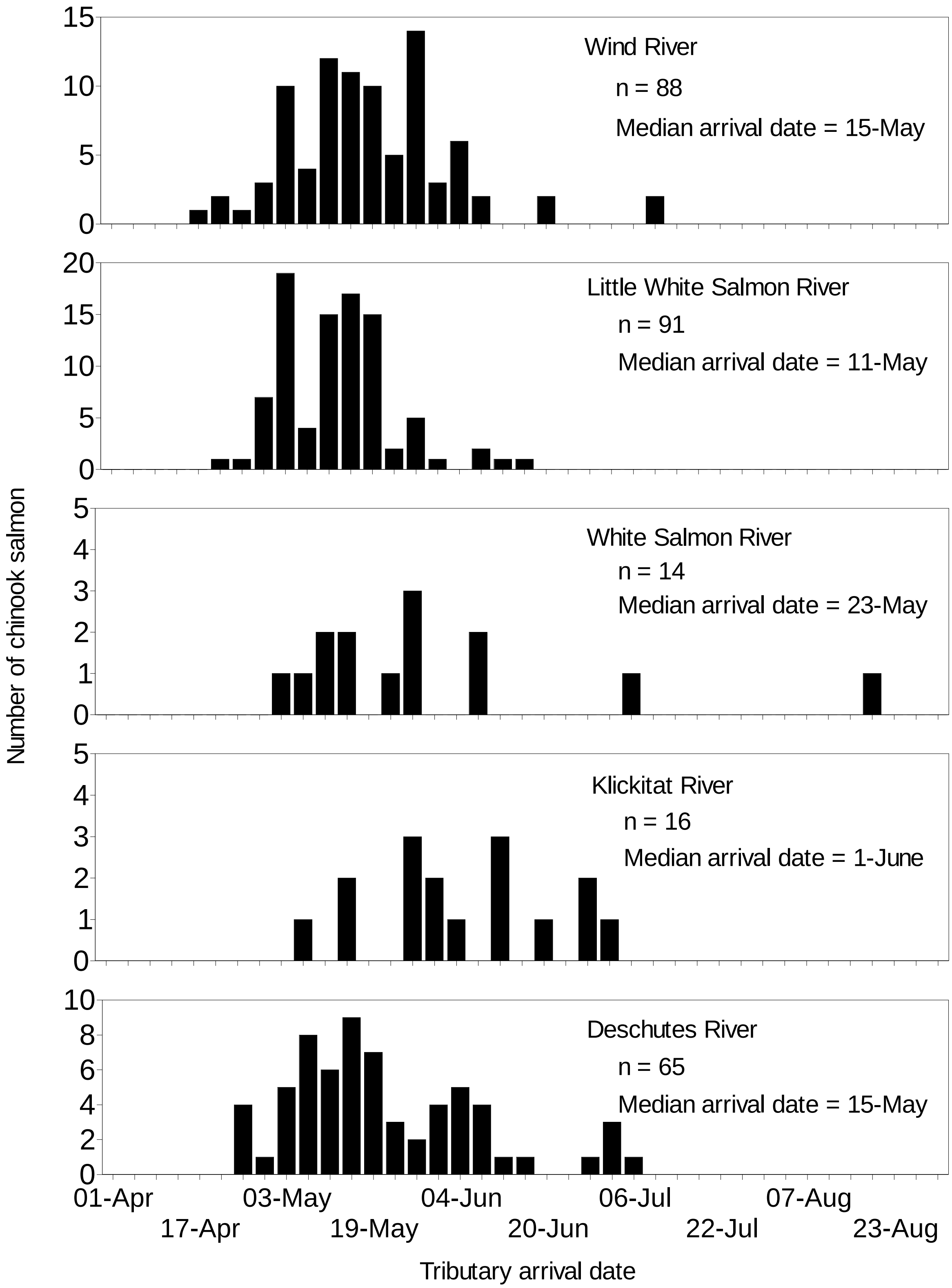

Figure 41. Number of chinook salmon and date of first record at fixed receiver sites at the mouths of the Wind, Little White Salmon, White Salmon, Klickitat and Deschutes rivers in 1996.

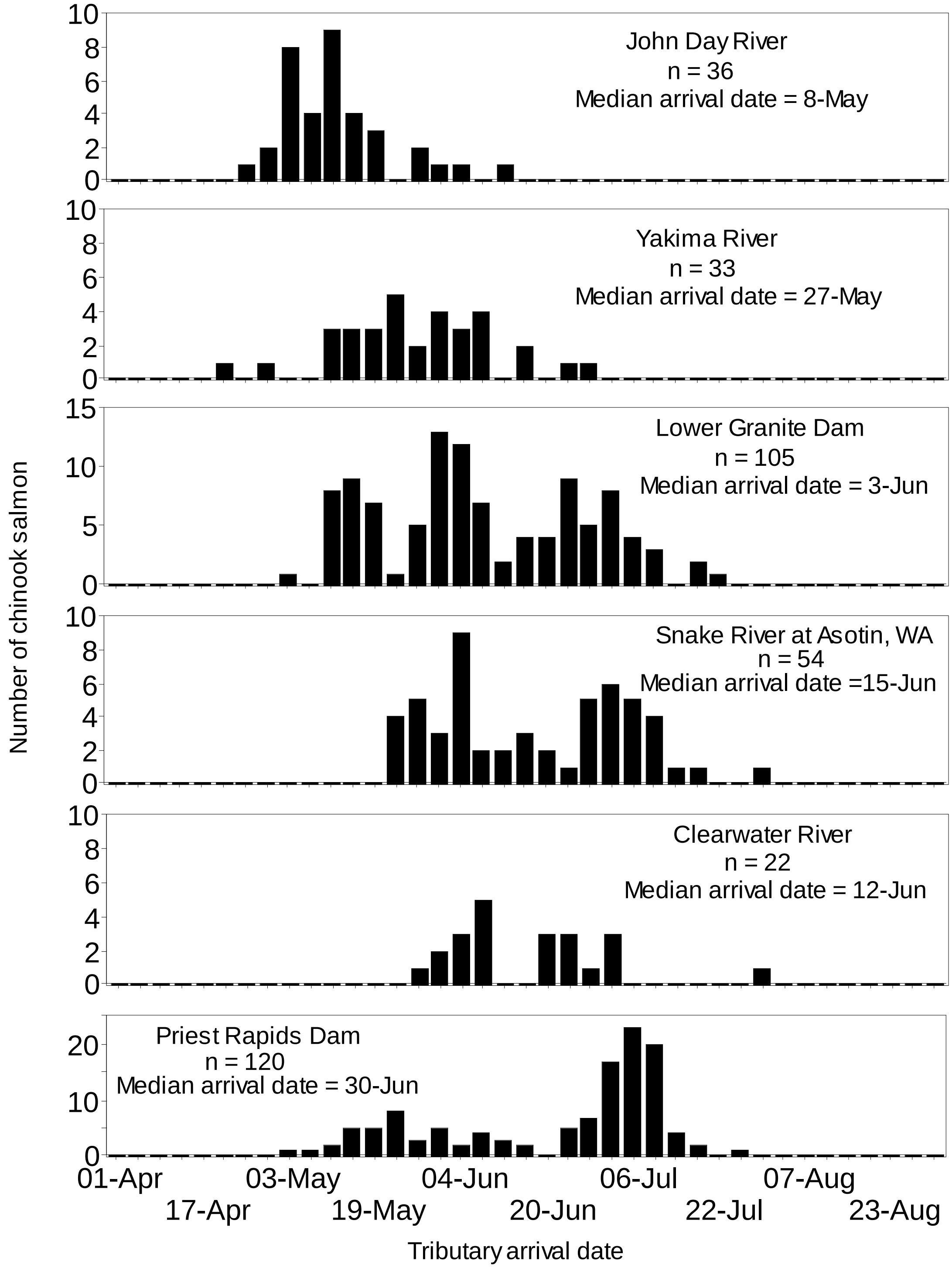

Figure 42. Number of chinook salmon and date of first record at fixed receiver sites at the mouths of the John Day, Yakima and Clearwater rivers, at Lower Granite and Priest Rapids dams and in the Snake River near Asotin, WA in 1996.

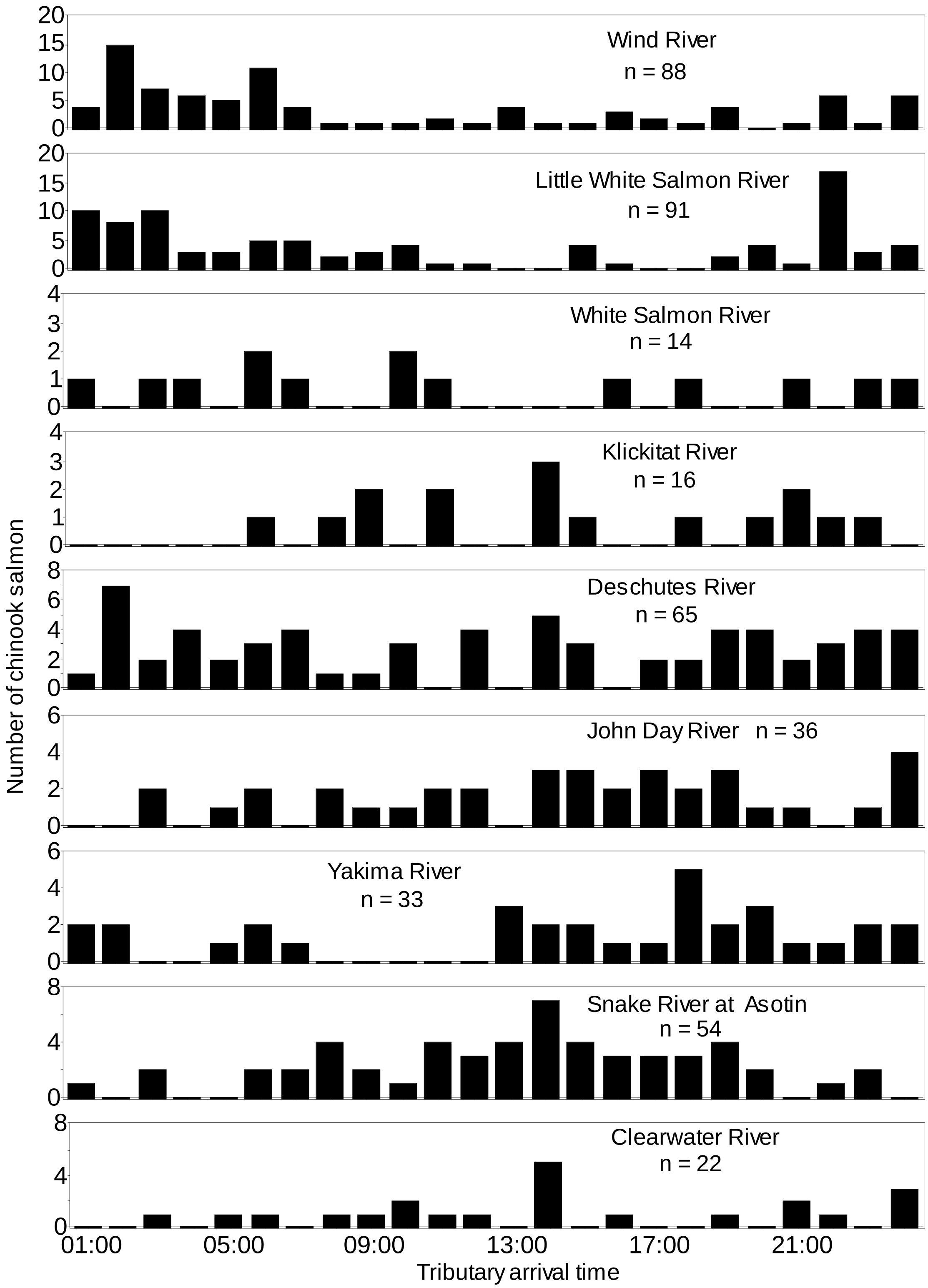

Figure 43. Diel arrival times for chinook salmon at tributaries, using the first record at receivers near mouths of tributaries and at the Snake River site near Asotin, WA in 1996.

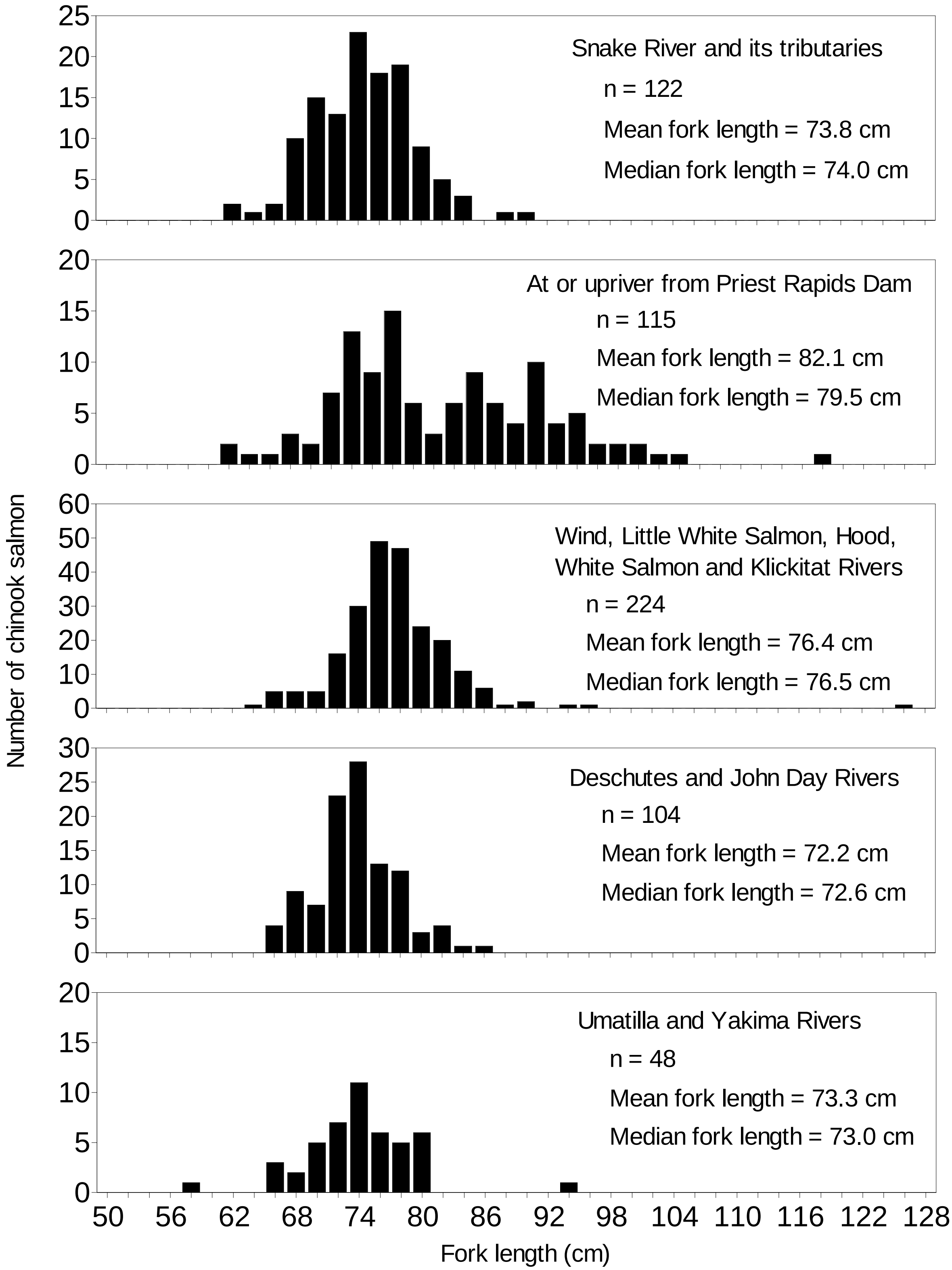

Figure 44. Length frequencies for chinook salmon with transmitters at time of tagging based on returns to the Snake River drainage, Priest Rapids Dam and lower Columbia River tributaries in 1996.

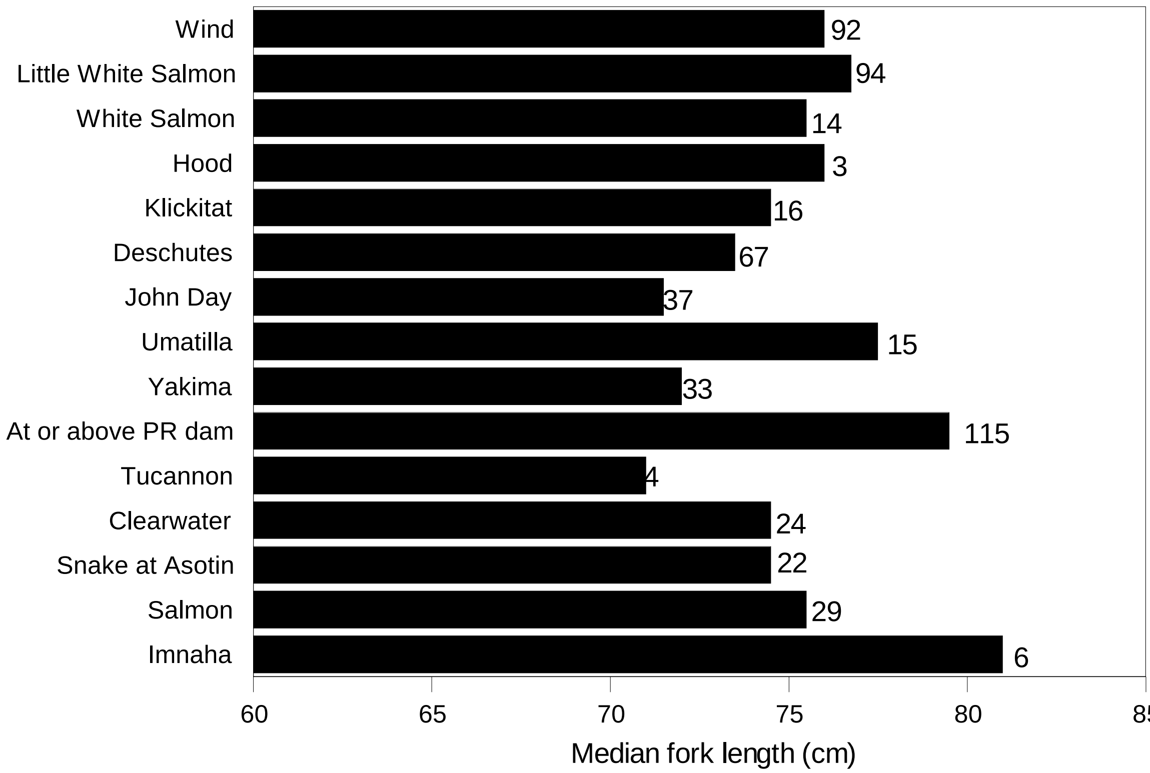

Figure 45. Median fork lengths for chinook salmon at time of tagging for fish that returned to individual tributaries or Priest Rapids Dam. Number of fish next to bar.

were tagged from April through early June, with a median date of 9-May.

Because telemetry and other records of radio-tagged chinook salmon were limited upriver from Priest Rapids Dam, we treated the dam as a surrogate measure for returns to the mid-Columbia River. It was clear from counts of all fish at Priest Rapids Dam and telemetry records of radio-tagged fish that distinct stocks of spring and summer chinook salmon passed the dam. The median tag date for fish considered spring chinook salmon was 6-May, and the median tag date for summer chinook salmon was 20-Jun (Figure 47). Distinctions between tag dates for spring- and summer-run fish were also evident in those fish recaptured in mid-Columbia tributaries. Fish that returned to the Icicle River were primarily spring chinook tagged in late April and early May. Fish that returned to the Wenatchee (not including Icicle River returns), Methow, and Similkameen rivers were all tagged in June. Returns to Wells Dam were about evenly split between spring- and summer-tagged fish (Figure 47).

Radio-tagged chinook salmon that returned to Lower Granite Dam were tagged at Bonneville Dam throughout the migration season, with a median tag date of 9-May and the highest number of tagged fish in late April (Figure 48). Returns to the Clearwater River were almost all spring chinook tagged in late April and May, with a median tag date of 6

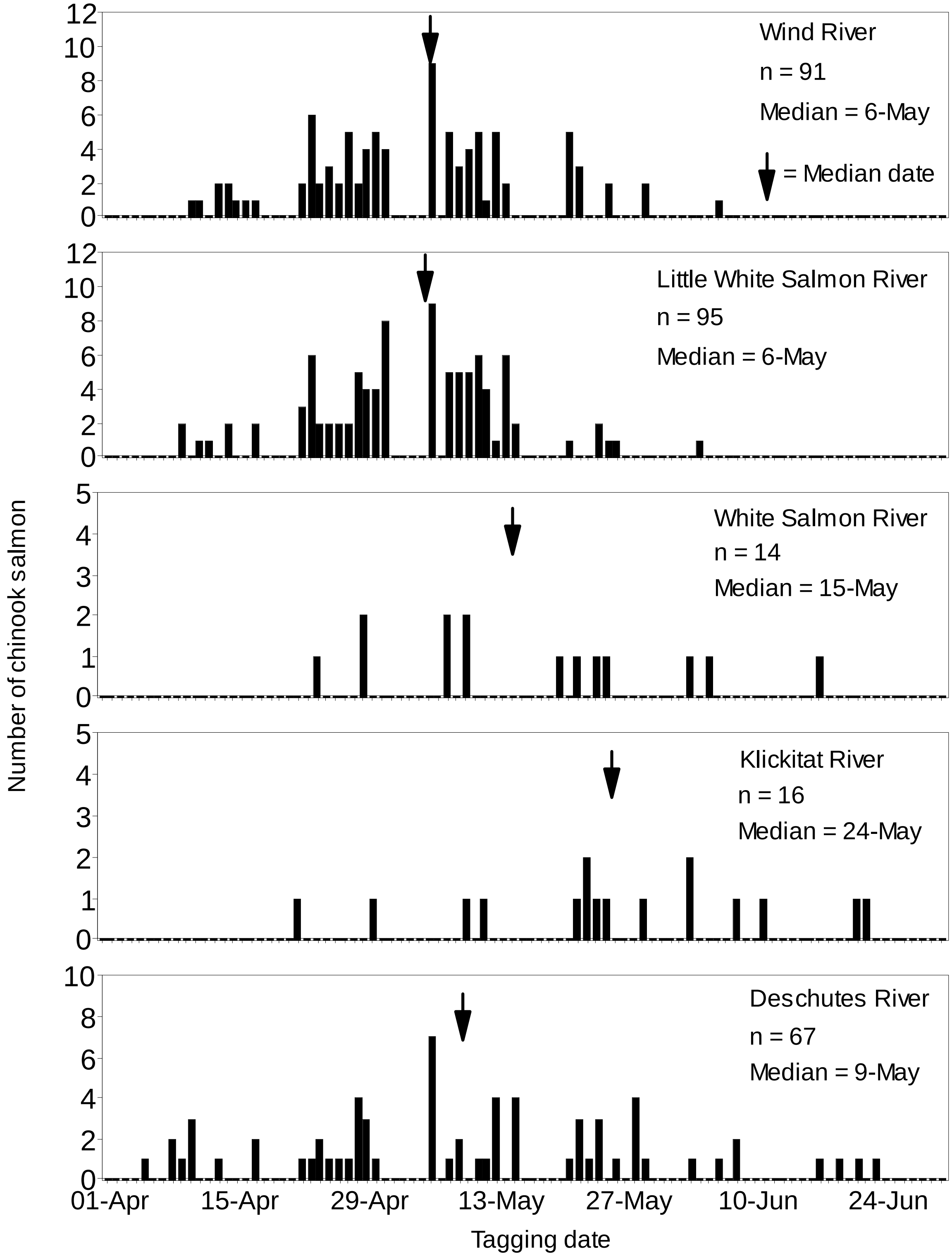

Figure 46. Tagging dates for spring and summer chinook salmon with last records in the Wind, Little White Salmon, White Salmon, Klickitat, and Deschutes rivers in 1996.

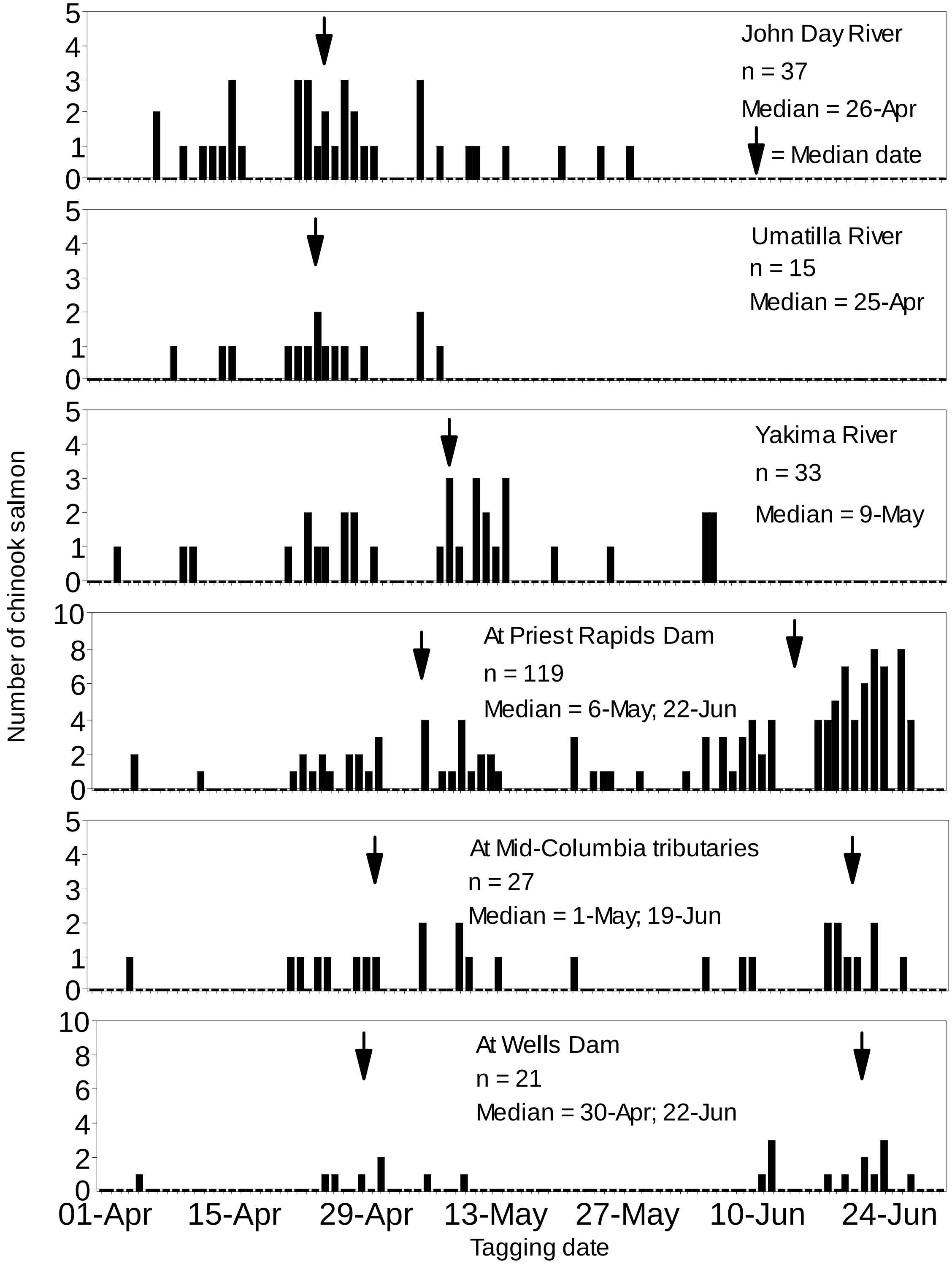

Figure 47. Tagging dates for spring and summer chinook salmon with last records in the John Day, Umatilla, and Yakima rivers and for fish that were recorded at Priest Rapids Dam, in mid-Columbia River tributaries upriver from Priest Rapids Dam and at Wells Dam in 1996.

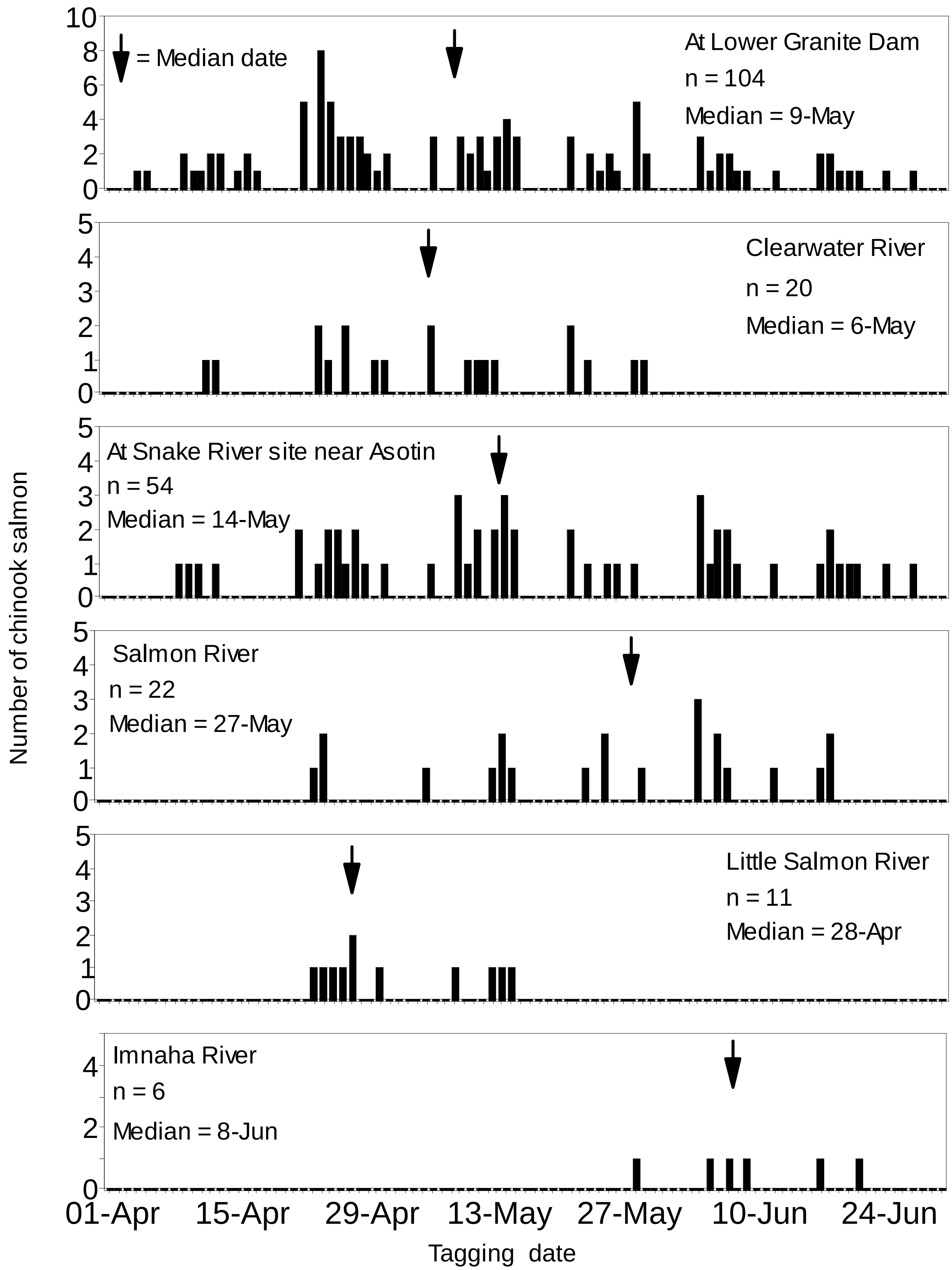

Figure 48. Tagging dates for spring and summer chinook salmon with last records in the Clearwater, Little Salmon, Salmon, and Imnaha rivers and for fish that were recorded at Lower Granite Dam or the Snake River site near Asotin, WA in 1996.

May. Fish that passed the Snake River receiver site near Asotin, WA were tagged throughout the migration. Because fish that returned to the Clearwater were not included, and many Salmon River fish were summer chinook, the median tag date for fish at the Asotin site was slightly later in the season (15-May) than the distribution at Lower Granite Dam.

Returns to the Salmon River (not including fish that returned to the Little Salmon River) were tagged from late April through June, with a median tag date of 27-May (Figure 48). Returns to the Little Salmon River were all spring chinook, tagged between mid-April and mid-May. Five of six radio-tagged fish that returned to the Imnaha River were summer chinook tagged in June (Figure 48).

Temporary Straying by Chinook Salmon with Transmitters

In 1996 (and in subsequent years), we observed that some salmon and a large number of steelhead enter lower Columbia River tributaries en route to final destinations at other locations. For 1996 chinook salmon with transmitters, we summarized the number of fish recorded at each lower Columbia River tributary, their final distribution and time spent in the tributary before migrating to different locations. Because of ESA issues, the potential for harvest of chinook salmon destined for the Snake River in lower Columbia River tributaries was of particular interest.

Of 125 fish recorded at Ice Harbor Dam, 25 (20%) were recorded in lower Columbia River tributaries, 10% entered the Little White Salmon River, 8% entered the John Day River, and from 1% to 3% entered the Hood, Klickitat or Deschutes rivers. Fixed receivers at the mouth of the Umatilla River were not in operation for most of the migration in 1996. Almost all chinook salmon that entered lower Columbia River tributaries but returned to the Snake River basin spent less than one day in any single downstream tributary, and most fish were recorded at fixed receiver sites in tributary mouths for less than one hour. By comparison, only seven (5%) of 154 chinook salmon recorded at either Priest Rapids Dam or the Yakima River were recorded at lower Columbia River tributaries, 3 each at the Little White Salmon and White Salmon rivers, one each at the John Day and Deschutes rivers, and all for less than 12 h.

Chinook salmon with transmitters moved between lower Columbia River tributaries, and many had stops of varying duration in multiple tributaries en route to their final destination. Of 108 chinook salmon recorded in the Wind River, 81% were last recorded there, 4% had last records at different lower Columbia River tributaries and 15% were last recorded in the Columbia River (Table 29). About 45% of fish recorded in the Wind River were also recorded at other lower Columbia River tributaries, primarily the Little White Salmon and White Salmon Rivers.

Of 198 fish recorded in the Little White Salmon River, 48% were last recorded there, 25% at different lower Columbia River tributaries, 17% in the main stem downstream from the Snake River, 6% in the Snake River drainage and 3% in the Yakima River or at/upriver from Priest Rapids Dam (Table 29). Fifty-four percent of the fish recorded in the Little

Table 29. Number of chinook salmon with transmitters recorded in lower Columbia River tributaries and percent with last records in lower Columbia River tributaries, the Snake River basin, or in the Columbia River or its tributaries upriver from the Snake in 1996.

	Wind River	L. White Salmon R.	White Salmon R.	Klickitat River	Deschutes River	John Day River
Number of fish recorded in tributary	108	198	88	30	78	48
Percent with last record in the tributary	81	48	16	53	86	77
Percent with last record in different lower Columbia River tributary	4	25	53	10	5	0
Percent with last record in Columbia main stem or at dams downstream from Snake R.	15	17	25	33	3	4
Percent with last record in Snake River drainage	0	6	3	3	5	17
Percent with last record in Yakima River or at/upriver from Priest Rapids Dam	0	3	2	0	1	2
Percent recorded in additional lower Columbia River tributaries	45	54	85	30	13	10
Percent recorded in Wind River	---	23	24	3	0	0
Percent recorded in Little White Salmon River	41	---	77	20	9	8
Percent recorded in White Salmon River	19	35	---	17	6	2
Percent recorded in Klickitat River	1	3	7	---	3	0
Percent recorded in Deschutes River	1	4	6	7	---	2
Percent recorded in John Day River	0	2	0	0	1	---

White Salmon River were also recorded at other tributaries, mostly in the White Salmon and Wind rivers.

Of 88 chinook salmon recorded in the White Salmon River, just 16% had last records there. More than half (53%) had last records in other lower Columbia River tributaries, 25% had last records in the Columbia River main stem downstream from the Snake River and 3% were in the Snake River (Table 29). Eighty-five percent of the fish recorded in the White Salmon River were also recorded in other lower Columbia River tributaries, 77% in the Little White Salmon River and 24% in the Wind River. Of 30 chinook salmon recorded in the Klickitat River, 53% had last records there. Another 33% had last records in the main stem downstream from the Snake River, 10% had last records in other lower Columbia River tributaries and 3% were last recorded in the Snake River basin (Table 29). Thirty percent of the fish recorded in the Klickitat River were also recorded at other lower Columbia River tributaries. About 77% of the chinook salmon recorded in John Day River and 86% of those recorded in the Deschutes River had their last records in those rivers. Five percent of those recorded in the Deschutes River and none of those recorded in the John Day River had last records in different lower Columbia River tributaries. Five percent of the fish recorded in the Deschutes River and 17% of those recorded in the John Day River were last recorded in the Snake River basin. Chinook salmon recorded in the Deschutes or John Day rivers were recorded at other lower Columbia River tributaries at much lower rates, 13% and 10%, respectively, than chinook salmon with last records in more downstream tributaries (Table 29).

Survival of Chinook Salmon with Transmitters

We assessed survival and final distribution of chinook salmon with transmitters in 1996 by recording fish as they passed receivers at dams and near the mouths of major tributaries, and as they were recorded by mobile trackers or were recaptured at hatcheries, weirs or in fisheries. We primarily determined final distribution by using the last known record for each chinook salmon (Figure 49). Distributions were also described for spring and summer chinook salmon, and chinook salmon with and without fin clips separately. In a few cases, chinook salmon with transmitters were recorded in tributaries before or during typical spawning times but had last records at main stem sites later in the fall. Some of these fish had probably spawned and subsequently drifted out of tributaries, or lost transmitters that were subsequently washed out of tributaries. In addition, it was clear that some chinook salmon were recaptured in fisheries and radio transmitters were not immediately returned to the ICFWRU. Transmitters were occasionally recorded as they were transported in autos or boats past receiver sites, and although we could sometimes identify that transmitters were not in fish, there was uncertainty about some transmitters and records at some fixed-site receivers. The problem of identifying records of transmitters that were being transported in vehicles versus those in chinook salmon was almost exclusively limited to the lower Columbia River, and particularly to records at the Wind, Little White Salmon, White Salmon, Deschutes and Klickitat rivers.

Using only last records for all 1996 spring and summer chinook salmon with transmitters, regardless of fallbacks, 66% survived to major tributaries and another 8% survived to the top of Priest Rapids Dam (Table 30). Fish with last records at Wells Dam, the Lower Granite trap (fish subsequently transported from dam or those released into ladder without transmitters), the mouth of the Clearwater River, the Snake River near Asotin, WA and the lower Deschutes River were considered to have reached tributary destinations, a broader definition than in previous years when we had more receivers and did more mobile tracking in tributaries used for spawning. Because of limited receiver coverage and few mobile-track records upriver from Priest Rapids Dam, we could not identify whether some chinook salmon that passed Priest Rapids survived to tributaries. For ease of comparison, we present two survival rates, one that included and one that did not include

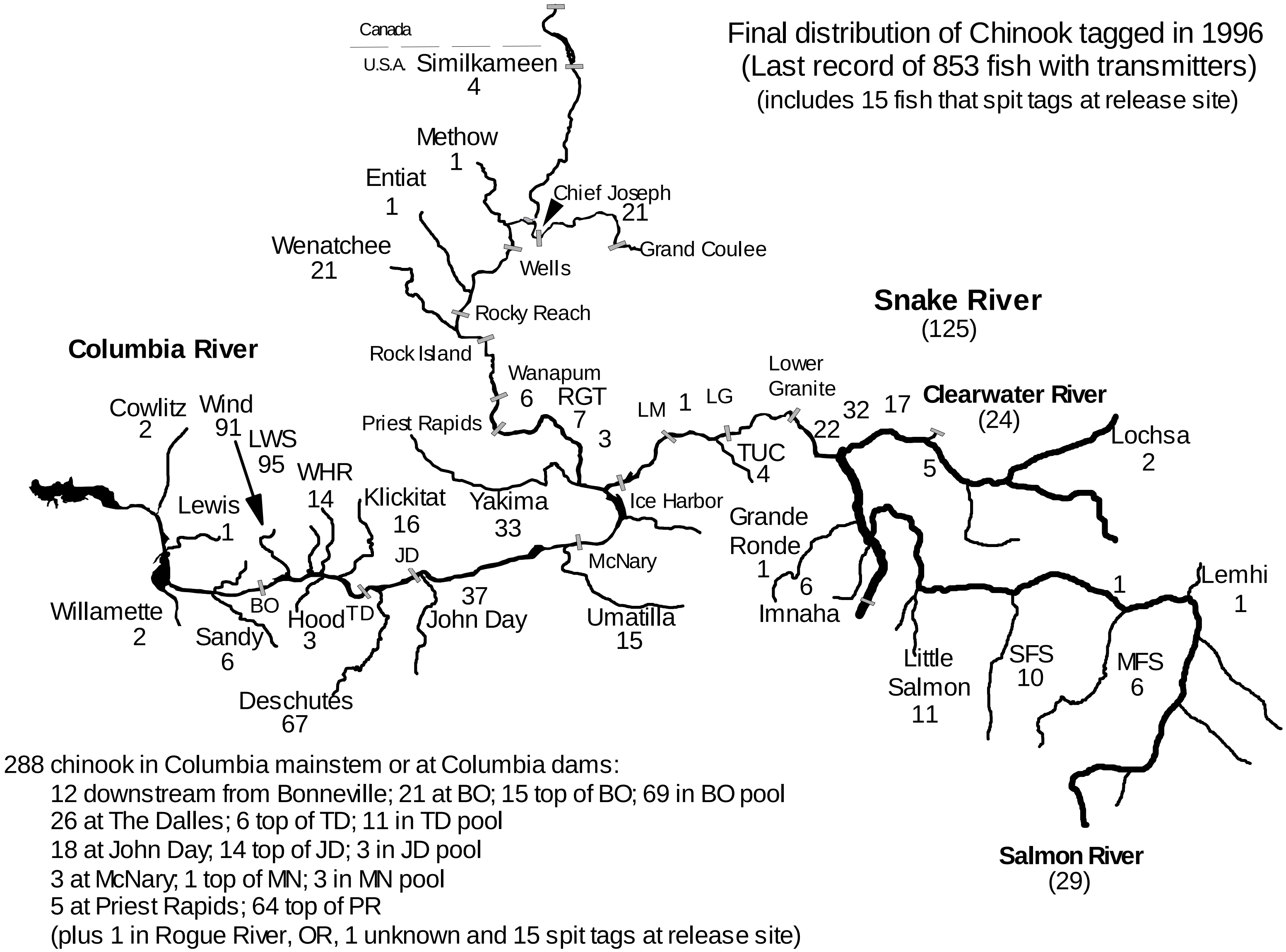

Figure 49. Final distribution of spring and summer chinook salmon outfitted with transmitters at Bonneville Dam in 1996 using last known records of each fish.

fish at the top of the Priest Rapids Dam as reaching tributary sites (Table 30). Based on survival rates for fish that passed other upriver dams, it is likely that many fish last recorded at the top of Priest Rapids Dam did reach a tributary.

Chinook salmon with transmitters without fin clips survived to tributaries at slightly higher rates (67%) than chinook salmon with fin clips (65%) (Table 30). When we include salmon last recorded at the top of Priest Rapids Dam, the survival rates were significantly ($P < 0.10$) different at 76% for unclipped chinook salmon and 70% for fin-clipped chinook salmon.

About 87% of summer chinook salmon survived to monitored tributaries or the top of Priest Rapids Dam versus 71% of spring chinook salmon, a significant ($P < 0.01$) difference (Table 30). In 1996, 36% of the summer chinook salmon were recorded at the top of Priest Rapids Dam as they migrated to mid Columbia River tributaries versus only 2% of the spring chinook salmon. Because the top of Priest Rapids Dam was a less stringent measure of survival than survival to tributaries, statistical inferences should be made with caution.

We suspected that last records for at least 15 chinook salmon were from transmitters that were being transported in vehicles, or the fish had spawned and drifted out of tributaries. All 15 fish had last records in the Columbia River main stem but we had other records for the fish when they were in the Deschutes, Klickitat, Little White Salmon, White Salmon, Wind or Sandy rivers at spawning time. If these fish were treated as successful returns, survival to major tributaries for all fish would have increased by 3% to 69%; survival would have increased by 2% for spring chinook salmon and 3% for summer chinook salmon (Table 31). Survival was significantly ($P < 0.01$) higher for summer chinook salmon than for spring chinook salmon.

Of 217 chinook salmon with last records at main stem or dam receiver sites other than the top of Priest Rapids Dam, 156 were unaccounted for, 43 were recaptured, and 18 had been recorded in tributaries before they were recorded back in the Columbia River. Two of the transmitters that were recovered were from fish recaptured at the Bonneville adult trap, one transmitter was found downstream from Bonneville Dam, one was recovered from an unknown location, and one was found in a Bonneville Dam fish ladder. The remaining 38 were recaptured in fisheries, and though exact locations were sometimes difficult to verify, 28 were reported recaptured in the Bonneville Dam pool, 4 in The Dalles Dam tailrace, 3 in The Dalles Dam pool, 1 in the John Day Dam tailrace, and 2 in the John Day Dam pool.

Last Recorded Distribution of Chinook Salmon with Transmitters

This summary of the final distribution of chinook salmon was based on our last telemetry or recapture record for each fish. Of 838 chinook salmon that retained transmitters after release in 1996, 11 (1%) had last records in tributaries downstream from Bonneville Dam, 12 (1%) were last recorded in the Columbia River downstream from the dam, 21 (3%) had last records at Bonneville Dam or it’s tailrace and one exited the Columbia River and was recaptured in the Rogue

Table 30. Number and percentage of chinook salmon with transmitters that did or did not survive to tributaries (including the Lower Granite Trap and Wells Dam) in 1996, using last records only; fish that had last records at the top of Priest Rapids Dam were treated as a special case.

	All salmon	Spring chinook	Summer chinook	Clipped chinook	Unclipped chinook
Number tagged	853	703	150	217	636
Transmitter spit at release	15	14	1	3	12
Number with transmitters	838	689	149	214	624
Number that survived to major tributaries (does not include top of Priest Rapids Dam)	557	481	76	139	418
Percent that survived to major tributaries (does not include top of Priest Rapids Dam)	**66**	**70**	**51**	**65**	**67**
Number last recorded at top of Priest Rapids Dam	64	11	53	10	54
Percent last recorded at top of Priest Rapids Dam	**8**	**2**	**36**	**5**	**9**
Number that survived to major tributaries (includes top of Priest Rapids Dam)	621	492	129	149	472
Percent that survived to major tributaries (includes top of Priest Rapids Dam)	**74**	**71**	**87**	**70**	**76**
Number not recorded at major tribs or at top of Priest Rapids Dam	217	197	20	65	152
Percent not recorded at major tribs or at top of Priest Rapids Dam	**26**	**29**	**13**	**30**	**24**

River, Oregon (Table 32). Almost 39% of the tagged fish had last records in the Columbia River or its tributaries between the top of Bonneville Dam and The Dalles Dam. Fifteen (2%) were last recorded at the top of Bonneville Dam, 64 (8%) in the Bonneville pool, 91 (11%) in the Wind River, 95 (11%) in the Little White Salmon River, 14 (2%) in the White Salmon River, 1 in the Hood River, 16 (2%) in the Klickitat River and 26 (3%) at The Dalles Dam.

Twenty-one percent (176 fish) of the chinook salmon had last records in the Columbia River or its tributaries between the top of The Dalles Dam and McNary Dam (Table 32). Six (1%) were last recorded at the top of The Dalles Dam, 11 (1%) in The Dalles Dam pool and 69 (8%) in the Deschutes River. Eighteen fish (2%) were last recorded at John Day Dam, 14 (2%) at the top of John Day, 37 (4%) in the John Day River, 3 in the John Day pool, 15 (2%) in the Umatilla River and 3 at McNary Dam.

Table 31. Number and percent of 838 chinook salmon that survived to major tributaries, based on last records, and/or evidence that fish spawned in a tributary but drifted to the main stem or was transported there. (Compare to Table 30.)

	All Chinook	Spring Chinook	Summer Chinook	Clipped Chinook	Unclipped Chinook
Number that retained transmitters after release	838	689	149	214	624
Number that survived to major tributaries (does not include top of Priest Rapids Dam)	575	495	81	140	435
Percent that survived to major tributaries (does not include top of Priest Rapids Dam)	**69**	**72**	**54**	**65**	**69**
Number that survived to major tributaries (includes top of Priest Rapids Dam)	639	506	134	150	489
Percent that survived to major tributaries (includes top of Priest Rapids Dam)	**76**	**73**	**90**	**70**	**78**

One tagged chinook salmon was last recorded at the top of McNary Dam. In the mid-Columbia River, 33 (4%) were last recorded in the Yakima River, 5 (1%) at Priest Rapids Dam and 64 (8%) at the top of Priest Rapids Dam. Thirteen fish (1%) were last recorded in the free-flowing section of the Columbia River between the McNary pool and Priest Rapids Dam, seven of which were recaptured at the Ringold Trap. Upriver from Priest Rapids Dam, 21 chinook salmon (3%) were last recorded in the Wenatchee River drainage, one each in the Entiat and Methow rivers and 4 in the Similkameen River. Another 21 chinook salmon (3%) were last recorded at Wells Dam or recaptured at Wells Hatchery (Table 32).

In 1996, 125 (15%) of the 838 tagged chinook salmon entered the Snake River. Seven fish were last recorded in the main stem or at dams between the mouth and Lower Granite Dam, and 4 were last recorded in the Tucannon River (Table 32). At Lower Granite Dam, 25 fish (3%) had last records at the adult trap (13 were transported to hatcheries including two without transmitters, and another 11 had lost transmitters and were released into the ladder), and 7 had last records at the top of the dam. Another 22 fish (3%) had last records in the main stem of the Snake at the fixed receiver site near Asotin, WA. Twenty-four (3%) had last records in the Clearwater drainage, 1 in the Grande Ronde River, 6 in the Imnaha River and 29 (3%) in the Salmon River drainage.

Summer chinook salmon that retained transmitters after release were primarily upriver fish; 79 (53%) of the 149 fish that retained transmitters had last records at or upriver from Priest Rapids Dam (Table 32). Four summer chinook salmon (3%) had last records in the Yakima River, and 23 (15%) had last records in the Snake River drainage: 11 in the Salmon River drainage, 5 in the Imnaha River and 5 in the Snake River near Asotin, WA. The remaining 47 chinook salmon tagged during June and July (32%), were distributed among lower Columbia River tributaries or had last records in the main stem or at dams. Six (4%) were last recorded in tributaries downstream from Bonneville Dam, 6 (4%) in the Klickitat River, and 8 (5%) in the Deschutes River. Nineteen summer chinook salmon (13%) were last recorded at lower Columbia River dams or in their pools (Table 32). Fish classified as summer chinook salmon made up more than 30% of the monitored returns in the Klickitat (38%), Salmon (38%) and Imnaha (83%) rivers and 65% of the chinook salmon with last records at or upriver from Priest Rapids Dam (Figure 50).

Fish classified as spring chinook salmon (tagged in April and May) were last recorded throughout the study area, but more than 70% of the 689 that retained transmitters after release were last recorded in the lower Columbia River or its tributaries. About 30% (205 fish) were last recorded in the Wind, Little White Salmon, White Salmon, and Klickitat rivers and 117 (17%) had last records at Bonneville Dam, in the Bonneville pool, or at The Dalles Dam (Table 32). Fifty-four (8%) had last records in the main stem between the top of The Dalles Dam and the McNary pool and 109 (16%) were last recorded in the Deschutes, John Day and Umatilla rivers. Another 102 spring chinook salmon (15%) were last recorded in the Snake River drainage, 24 (3%) in the Clearwater River and its tributaries, 18 (3%) in the Salmon River and its tributaries, and 31 (4%) at Lower Granite Dam or the adult trap at the dam. The remaining 77 spring chinook salmon (11%) were last recorded in the main stem Columbia River or its tributaries upriver from the mouth of the Snake River (Table 32). Spring chinook salmon made up more than 90% of the monitored returns to the Wind, Little White Salmon, Hood, John Day, Umatilla, Tucannon and Clearwater rivers, and 96% of the fish with last records at the Lower Granite Trap (Figure 50).

Salmon without fin clips made up 75% of the fish tagged in 1996 (Table 32). The percentage of unclipped fish was high because a large proportion of the spring chinook salmon run in 1996 was from lower Columbia River tributaries, and because the hatcheries in the Snake River drainage were the only ones that had clipped fins on all hatchery fish released in 1993 and 1994. Unclipped fish made up 90% or more of tagged salmon last recorded in the Wind, Little White, White Salmon, Hood, John Day, and Yakima rivers. A little more than half of the fish last recorded in the Klickitat and Deschutes rivers were unclipped. About 84% of the fish last recorded at or upstream from Priest Rapids Dam had not been clipped. In the Snake River drainage, where all smolts released from hatcheries were fin clipped starting in 1993, about 75% of the fish recorded in the Tucannon River were unclipped, as were 24% of the fish last recorded at the Lower Granite adult trap, 37% in the Clearwater River, 92% last recorded in the Snake River at Asotin, 48% in the Salmon River, and 67% in the Imnaha River.

Recaptures of Chinook Salmon with Transmitters

A minimum of 40% of the spring and summer chinook salmon outfitted with transmitters in 1996 were ultimately recaptured in fisheries, at hatcheries, traps or weirs, recovered at spawning grounds, or recovered from dead fish or transmitters found by people along the rivers. Forty percent is a minimum recapture rate because not all recaptured fish were reported to us, especially by sport and tribal fishers. At least 30% of the tagged

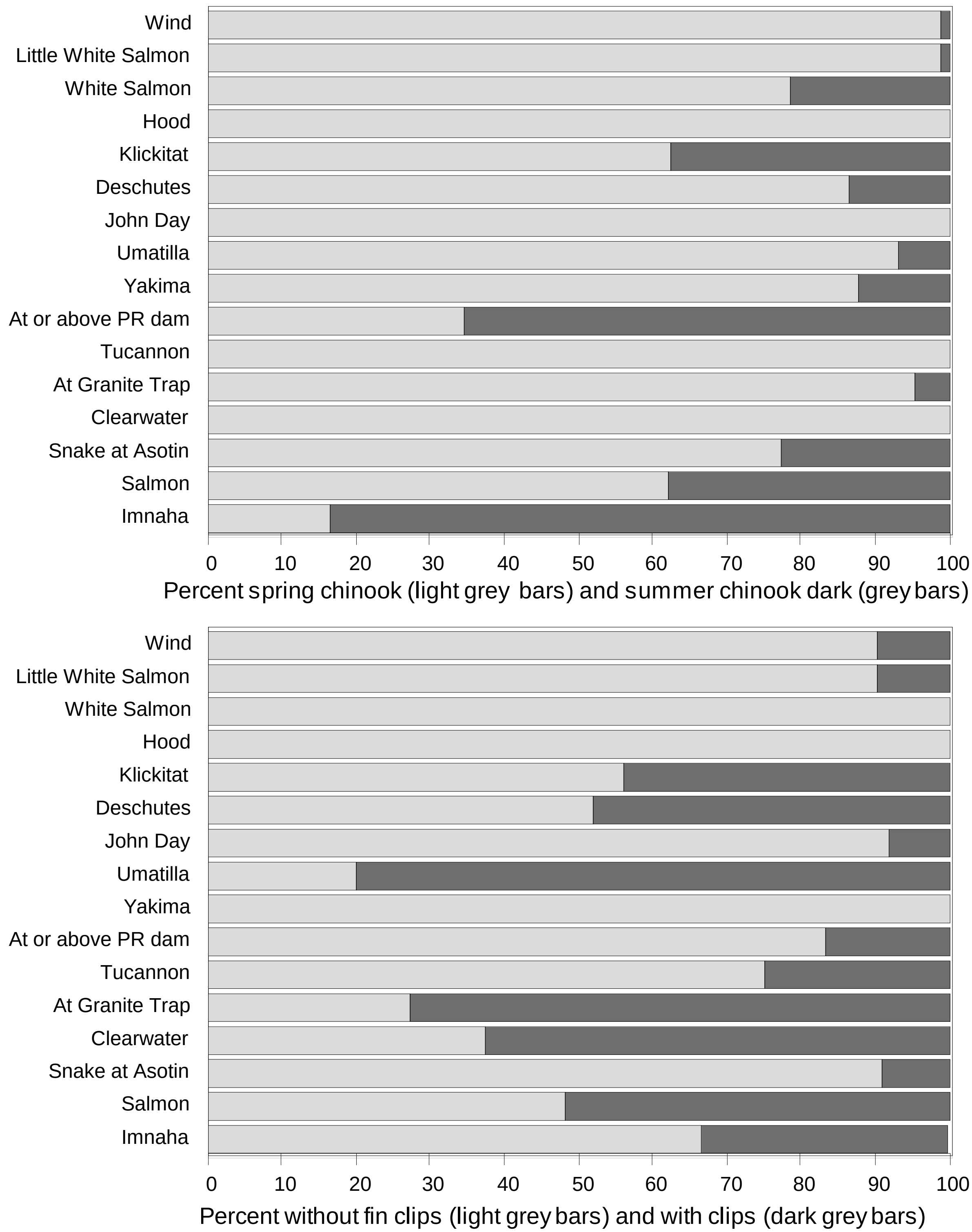

Figure 50. Percent of spring versus summer chinook salmon (upper graph), and percent of fish with or without fin clips that made up returns to major tributaries in 1996, based on last records of chinook salmon with transmitters.

summer chinook salmon and 41% of the spring chinook salmon were recaptured. Not included in the above were 18 fish recaptured in the Bonneville adult trap, and 85 fish recaptured at the Lower Granite adult trap that were released into ladders at the respective dams. At the Lower Granite Trap, another 13 chinook salmon recaptured had lost transmitters before recapture, and 14 were transported directly to hatcheries (including two without transmitters) (Table 33).

Without including the Bonneville and Lower Granite traps, we recovered 336 transmitters in 1996, 50 (15%) from sport fisheries, 44 (13%) from tribal fisheries, 204 (61%) at hatchery traps and weirs, and 38 (11%) at spawning grounds, in dead fish or transmitters found along river corridors (Table 33). Reported recaptures in sport fisheries accounted for 6.0% of the 838 chinook salmon that retained transmitters after release, and fish caught in tribal fisheries about 5.3%. Fish recaptured at hatcheries or other trap and weirs operated by researchers and managers made up 24.3% of fish released, and other types of recaptures amounted to 4.5% (Table 33).

Recaptured salmon at hatcheries on lower Columbia River tributaries accounted for 30% of the recaptures of salmon tagged in 1996, with 47 at Carson National Fish Hatchery on the Wind River, 36 at the Little White Salmon National Fish Hatchery and 18 at the Warm Springs National Fish Hatchery on the Deschutes River. When all types of recaptures in a drainage were combined, 46% were in the Wind, Little White Salmon or Deschutes river drainages; 65 (19%) were in the Wind River, 53 (16%) in the Little White Salmon River and 38 (11%) in the Deschutes River (Table 33).

Forty-two chinook salmon (13%) were recaptured in the main stem Columbia River downstream from McNary Dam, 4 at or downstream from Bonneville Dam, 30 in the Bonneville pool, 6 in The Dalles pool and 2 in the John Day pool. Most recaptures (76%) in the main stem were in tribal fisheries, 2 (4%) were in sport fisheries and the remaining 9 (20%) were found transmitters (Table 33). Fifteen additional chinook salmon recaptures came from the Klickitat, John Day, Hood, White Salmon, Sandy, and Santiam rivers, and 14 were recaptured at the Umatilla River weir at Three Mile Dam.

Not including the Lower Granite Trap recaptures, 41 chinook salmon (12%) were recaptured in the Snake River drainage. Three fish were recaptured in the Tucannon River, 17 in the Clearwater River drainage, 1 in the Grande Ronde River, 5 in the Imnaha River, and 15 in the Salmon River drainage (Table 33). Of the 41, 31 (76%) were recaptured at hatchery traps or fish weirs in rivers, 1 was recaptured in a tribal fishery, and 9 transmitters were recovered at spawning grounds or their transmitters were found along rivers.

In the mid Columbia River, 61 (18%) chinook salmon were recaptured. Two fish were recaptured in the Yakima River, 11 at or near the Ringold Trap and 2 at Priest Rapids Dam. Twenty-one fish were recaptured in the Wenatchee River drainage, 6 at spawning grounds in the Wenatchee River, 1 in a sport fishery in the Icicle River, and 14 at Leavenworth National Fish Hatchery on the Icicle River (Table 33). One chinook salmon was recaptured in the Entiat River, one in the Methow River, 4 in the Similkameen River, and 21 at the Wells Dam trap or hatchery.

Table 32. Final distribution by location based on last records of all chinook salmon, spring chinook and summer chinook salmon, and salmon with or without fin clips released with transmitters downstream from Bonneville Dam in 1996.

	All salmon	Spring chinook	Summer chinook	Clipped chinook	Unclipped chinook
All Fish	**853**	**703**	**150**	**217**	**636**
Lower Columbia River and Lower Columbia Tributaries					
Downstream from Bonn.	12	10	2	2	10
Spit at release site	15	14	1	3	12
Sandy River	6	2	4		6
Lewis River	1		1	1	
Cowlitz River	2	2			2
Willamette River	1		1		1
Santiam River	1	1			1
Rogue River (OR)	1	1			1
At Bonneville Dam	21	17	4	8	13
Top of Bonneville Dam	15	14	1	5	10
Bonneville Pool	64	60	4	18	46
Mouth of Wind River	4	1	3	2	2
Mouth of W. Salmon R.	1	1			1
Wind River	46	45	1	5	41
Carson Natl. Hatchery	45	45		4	41
Little White Salmon R.	59	58	1	6	53
LWS Natl. Hatchery	36	36		3	33
White Salmon River	14	11	3		14
Hood River	1	1			1
Powerdale Dam Trap	2	2			2
Klickitat River	16	10	6	7	9
At The Dalles Dam	26	24	2	7	19
Top of The Dalles Dam	6	6		3	3
The Dalles Pool	11	10	1	6	5
Deschutes River	38	33	5	15	23
Warm Springs Natl Hat.	17	16	1	8	9
Warm Springs River	1		1		1
Sherars Falls	2	2		1	1
Pelton Dam Trap	9	7	2	8	1
At John Day Dam	18	16	2	3	15
Top of John Day Dam	14	13	1	5	9
John Day Pool	3	2	1	1	2
John Day River	36	36		2	34
North Fork JDR	1	1		1	

Table 32. Continued.

	All salmon	Spring chinook	Summer chinook	Clipped chinook	Unclipped chinook
Umatilla River	1		1		1
Umatilla River Trap	14	14		12	2
At McNary Dam	3	3			3
Top of McNary Dam	1	1		1	
Unknown location	1	1		1	
Mid-Columbia River and Mid-Columbia Tributaries					
Yakima River	33	29	4		33
Ringold Trap	7	6	1	1	6
Near Ringold Trap	5	5			5
Hanford Reach	1	1			1
At Priest Rapids Dam	5	4	1	1	4
Top of Priest Rapids Dam	64	11	53	10	54
Wenatchee River	6		6	1	5
Icicle River	1	1			1
Leavenworth Natl. Hat.	14	13	1	2	12
Entiat River	1	1			1
Methow River	1		1		1
Similkameen River	4		4	4	
Wells Dam	17	7	10	2	15
Wells Hatchery	4	1	3	2	2
Snake River and Snake River Tributaries					
Mouth of Snake River	3	3			3
At Ice Harbor Dam	1	1			1
Top of Ice Harbor Dam	2	1	1	1	1
Tucannon River	4	4		1	3
Lower Monumental Pool	1	1			1
Top of Lower Granite Dam	7	7		2	5
Lower Granite Trap	25	24	1	19	6
Snake River at Asotin, WA	22	17	5	2	20
Clearwater River	6	6		3	3
Dworshak Natl. Hat.	10	10		8	2
Clear Creek	1	1			1
South Fork Clearwater R.					
Crooked River Weir	2	2		2	
Red River Weir	3	3		1	2
Lochsa River	1	1			1
Crooked Fork	1	1		1	

Table 32. Continued.

	All salmon	Spring chinook	Summer chinook	Clipped chinook	Unclipped chinook
Grande Ronde River					
Lookinglass Hatchery	1	1			1
Imnaha River	3	1	2	1	2
Imnaha River Weir	3		3	1	2
Little Salmon River	1	1		1	
Rapid River	1	1		1	
Rapid River Trap	9	9		8	1
South Fork Salmon R.	5		5	1	4
South Fork Weir	3	1	2	2	1
Secash River	1		1		1
Johnson Creek	1	1			1
Middle Fork Salmon R.					
Elk Creek	1	1		1	
Lemhi River	1	1			1
Upper Salmon River	3	2	1		3
Sawtooth Weir	3	1	2	1	2

We also summarized recapture information by four major basin Subsections: downstream from Bonneville Dam, from the top of Bonneville Dam to the McNary Dam tailrace, from the top of McNary Dam upriver through the mid-Columbia, and the Snake River basin. Of the 336 chinook salmon recaptured at locations other than the Bonneville and Lower Granite traps, 10 (3.0%) were recaptured downstream from Bonneville Dam, 221 (65.8%) between Bonneville and McNary dams, 63 (18.8%) in the mid Columbia River, and 41 (12.2%) in the Snake River basin (Table 34).

Nine of ten (90%) recaptures downstream from Bonneville Dam were spring chinook and nine did not have fin clips. One fish that was recaptured was out-of-basin at a hatchery in the Rogue River, OR. Three were recaptured in sport fisheries in downstream tributaries, and six were found in non-spawning areas (Table 34).

More than half of the chinook salmon recaptures in 1996 were in the lower Columbia River between Bonneville and McNary dams. Of 221 in this river section, 102 (46%) were recaptured at hatcheries, 25 (11%) in tributary traps or weirs, 42 (19%) in sport fisheries, 42 (19%) in tribal fisheries, 7 (3%) were transmitters found in tributaries, and 3 were found in non-spawning areas. Almost 96% (212 of 221 fish) of the recaptures in the Bonneville-to-McNary section of the Columbia River were spring chinook salmon (Table 34), and 74% did not have fin clips (Table 35).

In the mid Columbia River section, 48% of the 63 recaptures were at hatcheries, 24% in tributary traps or weirs, and 19% were found in tributaries (Table 34). Six fish (10%) were recaptured in fisheries, five in sport fisheries and 1 in a tribal fishery.

Table 33. Number and percent of chinook salmon released with transmitters downstream from Bonneville Dam in 1996 with recaptures at all sites, recaptured and reported in sport and tribal fisheries, at hatcheries, weirs and other traps, and those recaptured in spawning areas, or found along rivers.

	All recaps	Sport fisheries	Tribal fisheries	Hatcheries weirs, traps	Other[a]
All Fish, incl Bonn, LGr traps	465	50	44	333	38
Without Bonn,LGr traps	336	50	44	204	38
Percent of 336	100	14.9	13.1	60.7	11.3
Percent of 838	40.1	6.0	5.3	24.3	4.5
Lower Columbia and Lower Columbia Tributaries					
Downstream from Bonn. Dam	2				2
At release site	4				4
Sandy River	2	2			
Willamette River					
Santiam River	1	1			
Rogue River (OR)	1			1	
Bonneville Trap, released	18			18	
Bonn. Trap, pulled trans.	1			1	
Found trans. in Bonn ladder	1			1	
Bonneville Pool	30	1	27		2
Wind River	65	14	1	47	3
Little White Salmon	53	12	4	36	1
White Salmon River	4	4			
Hood River	2			2	
Klickitat River	5	2	1	2	
The Dalles Pool	6	1	5		
Deschutes River	38	8	2	26	2
John Day Pool	2		2		
John Day River	1				1
Umatilla River Trap	14			14	
Unknown	1				1
Mid-Columbia River and Mid-Columbia Tributaries					
Yakima River	2		1		1
Ringold Trap	7			7	
Near Ringold Trap	4	3			1
At Priest Rapids Dam	2			2	
Wenatchee River	6				6
Icicle River	15	1		14	

Table 33. Continued.

	All recaps	Sport fisheries	Tribal fisheries	Hatcheries weirs, traps	Other[a]
Entiat River	1			1	
Methow River	1				1
Similkameen River	4	1			3
Wells Dam	21			21	
Snake River and Snake River Tributaries					
Tucannon River	3				3
Lower Granite Trap	110			110	
(13 transported to hatcheries and 13 had lost transmitters)					
Clearwater River	11			10	1
South Fork	5			5	
Lochsa River	1				1
Grande Ronde River	1			1	
Imnaha River	5			3	2
Little Salmon River	8			7	1
South Fork Salmon River	4		1	2	1
Upper Salmon River	3			3	

[a] Other includes recaptures at spawning grounds, found transmitters or found dead fish.

Fifty-nine percent of recaptures in the mid-Columbia were spring chinook and 43% were summer chinook. Most (81%) of the mid-Columbia recaptures were fish that did not have fin clips (Table 35).

Most of the 41 recaptures in the Snake River basin subsection were in tributaries at hatcheries (37%) or traps and weirs (39%) (Table 34). Another 9 fish (22%) were from transmitters found in tributaries. There was no legal sport fishery and one fish was recaptured in a tribal fishery. Sixty-three percent of the fish recaptured in the Snake River had fin clips when tagged (Table 35).

Fate of Chinook Salmon with Transmitters

In addition to summaries of last recorded location, and type and location of recapture, we made best estimates of the fate of each radio-tagged chinook salmon. Our best estimate summary differed from last record summaries because last record locations did not always reflect the fact that fish survived to enter tributaries; some fish moved out of tributary sites after time for spawning and were recorded downstream, some transmitters were transported from tributaries to the Columbia River in vehicles, and there were fallbacks at dams just prior to last records that were misleading (Table 31). In the best-estimate summaries of chinook salmon fate, we calculated total

Table 34. Number of spring and summer chinook salmon released in 1996 downstream from Bonneville Dam with transmitters that were recaptured or the transmitter was found somewhere in the basin and was returned to us, and the number recaptured and percent of total recaptures in various locations.

	All salmon		Spring salmon		Summer salmon	
	Number	Percent	Number	Percent	Number	Percent
Number released and % returned	853	39.4	703	41.4	150	30.0
Transmitter returned from:						
Downstream from Bonneville	**10**	**1.2**	**9**	**1.3**	**1**	**0.7**
Hatcheries	1	0.1	1	0.1		
Sport fishery	3	0.4	3	0.4		
Found in non spawning area	6	0.7	5	0.7	1	0.7
Bonneville to McNary dams	**221**	**25.9**	**212**	**30.2**	**9**	**6.0**
Hatcheries	102	12.0	101	14.4	1	0.7
Weirs/traps in tributaries	25	2.9	23	3.3	2	1.3
Sport fishery	42	4.9	40	5.7	2	1.3
Tribal fishery	42	4.9	39	5.5	3	2.0
Found in tributary	7	0.8	6	0.9	1	0.7
Found in non spawning area	3	0.4	3	0.4		
Mid-Columbia River	**63**	**7.4**	**37**	**5.3**	**26**	**17.3**
Hatcheries	30	3.5	16	2.3	14	9.3
Weirs/traps in tributaries	15	1.8	14	2.0	1	0.7
Sport fishery	5	0.6	4	0.6	1	0.7
Tribal fishery	1	0.1	1	0.1		
Found in tributary	12	1.4	2	0.3	10	6.7
Snake River basin	**41**	**4.8**	**32**	**4.6**	**9**	**6.0**
Hatcheries	15	1.8	13	1.8	2	1.3
Weirs/traps in tributaries	16		12	1.7	4	2.7
Tribal fishery	1	0.1			1	0.7
Found in tributary	9		7	1.0	2	1.3
Recaptured at unknown location	**1**	**0.1**	**1**	**0.1**		

escapement to tributaries and hatcheries, total reported harvest, and total unaccounted for fish. We also calculated escapement and harvest, and listed the approximate distribution of unaccounted for spring and summer chinook salmon and fin-clipped and unclipped fish.

The final distribution for all radio-tagged spring and summer chinook salmon based on our best estimate of the fate of each fish was 6.2% downstream from Bonneville Dam, 59.6% between the top of Bonneville Dam and the McNary Dam tailrace, 19.2% in the mid-Columbia upstream from McNary Dam, and 14.7% in the Snake River basin (Table 36). Escapement was 37% to tributaries, 22.6% to hatcheries, 7.5% to the top of Priest Rapids Dam, and 1.3% at Lower Granite trap without transmitters, for a total escapement of 68.5% (Figure 51).

Another 10.6% were reported recaptured in sport and tribal fisheries. Known regurgitated transmitters downstream from Bonneville Dam or transmitters found in non-spawning areas made up 2.3% of the fish, and 18.3% were

Table 35. Number of chinook salmon with and without fin clips released in 1996 downstream from Bonneville Dam with transmitters that were recaptured or the transmitter was found somewhere in the basin and was returned to us, and the number of fish recaptured and percent of total recaptures in various locations.

	All salmon		Fin-clipped salmon		Unclipped salmon	
	Number	Percent	Number	Percent	Number	Percent
Number released and % returned	853	39.4	217	44.7	636	37.6
Transmitter returned from:						
Downstream from Bonneville	**10**	**1.2**	**1**	**0.5**	**9**	**1.4**
Hatcheries	1	0.1			1	0.2
Sport fishery	3	0.4			3	0.5
Found in non spawning area	6	0.7	1	0.5	5	0.8
Bonneville to McNary dams	**221**	**25.9**	**57**	**26.3**	**164**	**25.8**
Hatcheries	102	12.0	16	7.4	86	13.5
Weirs/traps in tributaries	25	2.9	19	8.8	6	0.9
Sport fishery	42	4.9	10	4.6	32	5.0
Tribal fishery	42	4.9	10	4.6	32	5.0
Found in tributary	7	0.8	6	2.8	1	0.2
Found in non spawning area	3	0.4			3	0.5
Mid- Columbia River	**63**	**7.4**	**12**	**5.5**	**51**	**8.0**
Hatcheries	30	3.5	6	2.8	24	3.8
Weirs/traps in tributaries	15	1.8	1	0.5	14	2.2
Sport fishery	5	0.6	1	0.5	4	0.6
Tribal fishery	1	0.1			1	0.2
Found in tributary	12	1.4	4	1.8	8	0.9
Snake River basin	**41**	**4.8**	**26**	**12.0**	**15**	**2.4**
Hatcheries	15	1.8	9	4.1	6	0.9
Weirs/traps in tributaries	16		12	5.5	4	0.6
Tribal fishery	1	0.1	1	0.5		
Found in tributary	9		4	1.8	5	0.8
Recaptured at unknown location	**1**	**0.1**			**1**	**0.5**

unaccounted for throughout the study area (Table 36).

Of the 703 chinook salmon we designated as spring chinook, we determined that 6.0% ended up downstream from Bonneville Dam, 67.6% in the lower Columbia between Bonneville Dam and the tailrace of McNary Dam, 11.4% in the mid-Columbia, and 14.7% in the Snake River basin (Table 36). Sixty-five percent of the spring chinook salmon ended up as escapements, 37.1% to tributaries, 24.6% to hatcheries, 1.6% past Priest Rapids Dam, and 1.4% recaptured at the Lower Granite trap and released without transmitters (Figure 52). Another 11.8% were recaptured in sport and tribal fisheries. Fish that we know regurgitated their transmitters downstream from Bonneville Dam or their transmitters were found in non-spawning areas accounted for 2.7% of the spring chinook salmon, and 20.3% were unaccounted for throughout the study area.

Table 36. Our best estimate of the fate of 853 spring and summer chinook salmon released in 1996 downstream from Bonneville Dam with transmitters with the numbers released, numbers and percents of total that ended up in the various sections of the Columbia River basin.

	All salmon		Spring salmon		Summer salmon	
	Number	Percent	Number	Percent	Number	Percent
Number released	853	100	703	100	150	100
Downstream from Bonneville	**53**	**6.2**	**42**	**6.0**	**11**	**7.3**
Entered a tributary	9	1.1	3	0.4	6	0.4
Sport fishery	3	0.4	3	0.4		
Regurgitated transmitter	15	1.8	14	2.0	1	0.7
Found in non-spawning area	3	0.4	3	0.4		
Unaccounted for	23	2.7	19	2.7	4	2.7
Bonneville to McNary dams	**508**	**59.6**	**475**	**67.6**	**33**	**22.0**
Entered a tributary	199	23.3	181	25.7	18	12.0
Recaptured at hatchery	112	13.1	109	15.5	3	2.0
Sport fishery	41	4.8	39	5.5	2	1.3
Tribal fishery	39	4.6	36	5.1	3	2.0
Found in non-spawning area	2	0.2	2	0.3		
Unaccounted for	115	13.5	108	15.4	7	4.7
Mid-Columbia River	**164**	**19.2**	**80**	**11.4**	**84**	**56.0**
Entered a tributary	44	5.2	30	4.3	14	9.3
Recaptured at hatchery	46	5.4	31	4.4	15	10.1
Sport fishery	5	0.6	4	0.6	1	0.7
Tribal fishery	1	0.1	1	0.1		
Top of Priest Rapids Dam	64	7.5	11	1.6	53	35.3
Unaccounted for	4	0.5	3	0.4	1	0.7
Snake River basin	**125**	**14.7**	**103**	**14.7**	**22**	**14.7**
Entered a tributary	64	7.5	47	6.7	17	11.3
Recaptured at hatchery[a]	35	4.1	33	4.7	2	1.3
Tribal fishery	1	0.1			1	0.7
At L. Granite Trap, no transmitter	12	1.2	11	1.6	1	0.7
Unaccounted for	14	1.6	13	1.8	1	0.7
Other[b]	**3**	**0.4**	**3**	**0.4**		
	Basin-wide summary					
Recorded in tributaries	**316**	**37.0**	**261**	**37.1**	**55**	**36.7**
Recaptured at hatcheries	**193**	**22.6**	**173**	**24.6**	**20**	**13.3**
Reported harvest	**90**	**10.6**	**83**	**11.8**	**7**	**4.7**
Last record at Lower Granite trap[c]	**11**	**1.3**	**10**	**1.4**	**1**	**0.7**
Last record at Priest Rapids Dam	**64**	**7.5**	**11**	**1.6**	**53**	**35.3**
Regurgitated transmitters	**20**	**2.3**	**19**	**2.7**	**1**	**0.7**
Other[b]	**3**	**0.4**	**3**	**0.4**		
Transmitters unaccounted for	**156**	**18.3[d]**	**143**	**20.3**	**13**	**8.7**

[a] includes 14 spring chinook recaptured at Lower Granite trap, transported to Lookingglass Hatchery; 2 without transmitter.

[b] 1 fish recaptured at Rogue River hatchery; 1 transmitter removed from fish at Bonneville adult trapping facility; 1 fish recaptured at unknown location.

[c] lost transmitters before recapture at Lower Granite Dam, not recorded or transported upstream of trap.

[d] includes 7 fish that passed Lower Granite Dam with transmitters that were not recorded upstream.

Our best estimate of the fate for 150 fish designated as summer chinook salmon was that 7.3% ended up downstream from Bonneville Dam, 22.0% in the river and tributaries between Bonneville Dam and the tailrace of McNary Dam, 56.0% in the mid Columbia River, and 14.7% in the Snake River basin. A high percentage of summer chinook salmon escaped to tributaries (36.7%), to hatcheries (13.3%), past Priest Rapids Dam (35.3%), and 0.7% were recaptured at the Lower Granite trap without a transmitter and then released for a total escapement of 86.0% (Table 36). Another 4.7% of the summer chinook salmon were recaptured in sport or tribal fisheries and 8.7% were unaccounted for (Figure 52). Escapement was significantly higher and proportion unaccounted for significantly lower ($P < 0.01$) for summer chinook salmon than for spring chinook salmon.

As described previously, many hatchery fish from lower- and mid-Columbia River hatcheries were not fin clipped, whereas hatchery chinook salmon produced in the Snake River basin should have been clipped for the 1996 return year. Of 217 chinook salmon tagged that had fin clips, 6.0% ended up downstream from Bonneville Dam, 55.8% in the lower Columbia River and tributaries, 11.1% in the mid-Columbia River, and 26.3% in the Snake River basin (Table 37). Sixty-four percent of the fin-clipped salmon escaped to tributaries (29.0%), hatcheries (27.6%), past Priest Rapids Dam (4.6%), and were recaptured at Lower Granite adult trap and released without transmitters (2.3%). Almost 10% of the fin-clipped fish were reported as recaptures in sport and tribal fisheries, and 1.8% were fish that regurgitated transmitters at the release site or their transmitters were found in non-spawning areas. About 23.5% of the fin- clipped salmon were unaccounted for.

For the 636 tagged chinook salmon without fin clips, 6.3% ended up downstream from Bonneville Dam, 60.8% in the lower Columbia River and tributaries, 22.0% in the mid- Columbia River, and 10.7% in the Snake River basin (Table 37). Escapement for unclipped fish was 39.8% to tributaries, 20.8% to hatcheries, 8.5% past Priest Rapids Dam, and 0.9% were recaptured without transmitters at the Lower Granite trap for a total escapement of 70.0%, significantly ($P < 0.10$) higher than the 63.6% escapement for fin-clipped fish. About 10.8% of the unclipped fish were reported as recaptures in sport and tribal fisheries, and 2.5% of the unclipped fish were known to have regurgitated tags at the release site or had transmitters found in non-spawning areas. A significantly ($P < 0.05$) lower proportion of the unclipped salmon (16.5%) were unaccounted for than of the fish with fin clips (23.5%) (Table 37).

The 53 transmitters (6.2%) we determined were downstream from Bonneville Dam included 23 (43%) unaccounted for fish, 15 (28%) known regurgitated tags at the release site, 9 (17%) fish that entered tributaries, 3 (6%) recaptures in the sport fishery, and 3 (6%) found transmitters at non-spawning areas (Table 36; Figure 53). Forty-two of the 53 (79%) transmitters recovered from downstream Bonneville Dam were from spring chinook salmon and 75% were from fish without fin clips. By category, the fate of spring chinook salmon downstream from Bonneville Dam was similar to the pattern observed for spring and summer fish combined (Figure 54).

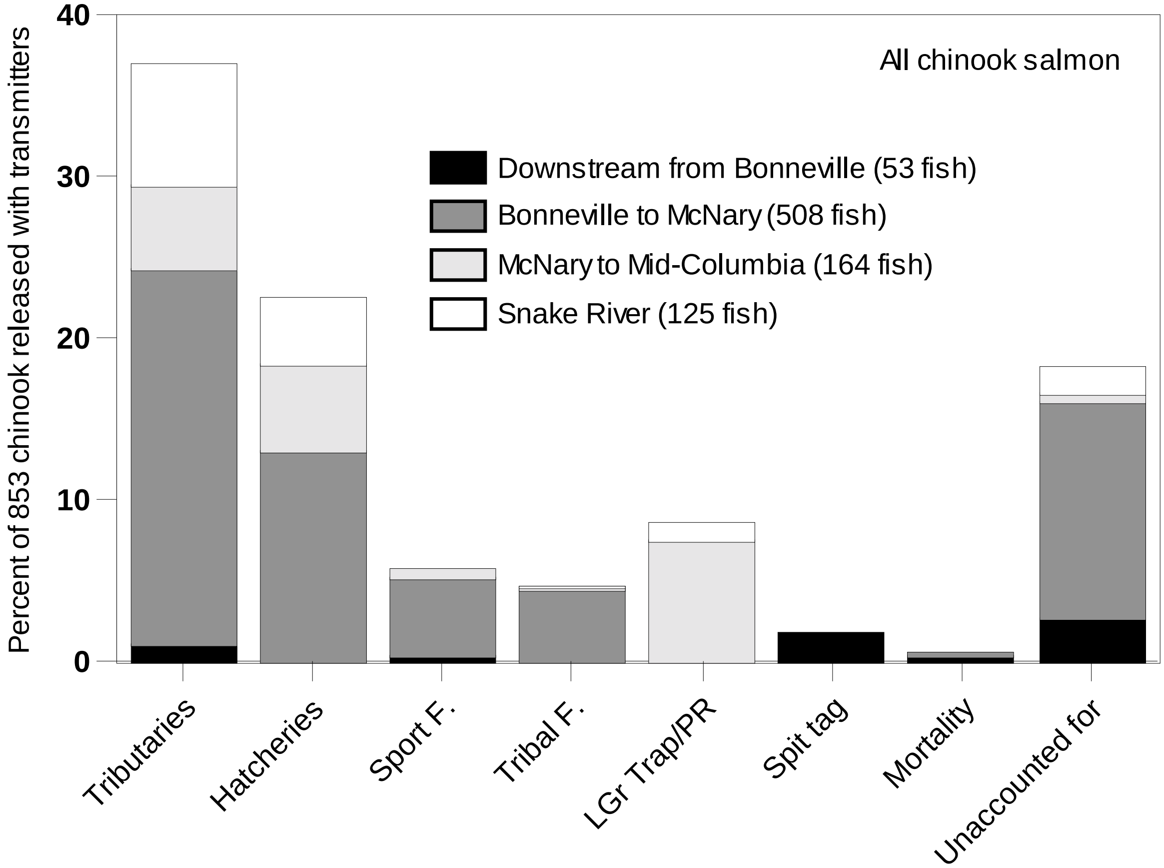

Figure 51. Our best estimate of the percentage of chinook salmon with transmitters in 1996 that ended up in tributaries, at hatcheries, in fisheries, passing Priest Rapids Dam, transported from the Lower Granite trap, were found after they regurgitated their transmitters, or were unaccounted for.

More than half of the chinook salmon tagged in 1996 ended up in the Columbia River or its tributaries between Bonneville and McNary dams. Of the 508 fish (59.6% of all tagged fish) that ended up in the section, 199 (39%) entered tributaries, 112 (13%) were recaptured at hatcheries, 80 (16%) were reported as recaptures in sport and tribal fisheries, and 115 (13.5%) were unaccounted for (Figure 53). The escapement to tributaries in the lower Columbia River section was 23.3% of the 853 salmon outfitted with transmitters, the largest proportion of the run in any category (Table 36). Almost 94% of the transmitters returned from the lower Columbia River section were spring chinook salmon (Table 36), and about 76% were fish without fin clips (Table 37).

Of the 164 fish that ended up in the mid Columbia River section , 44 (27%) returned to tributaries, 46 (28%) were recaptured at hatcheries, and 64 (39%) were last recorded at the top of Priest Rapids Dam (Table 36, Figure 53). About 49% of the fish that returned to the mid-

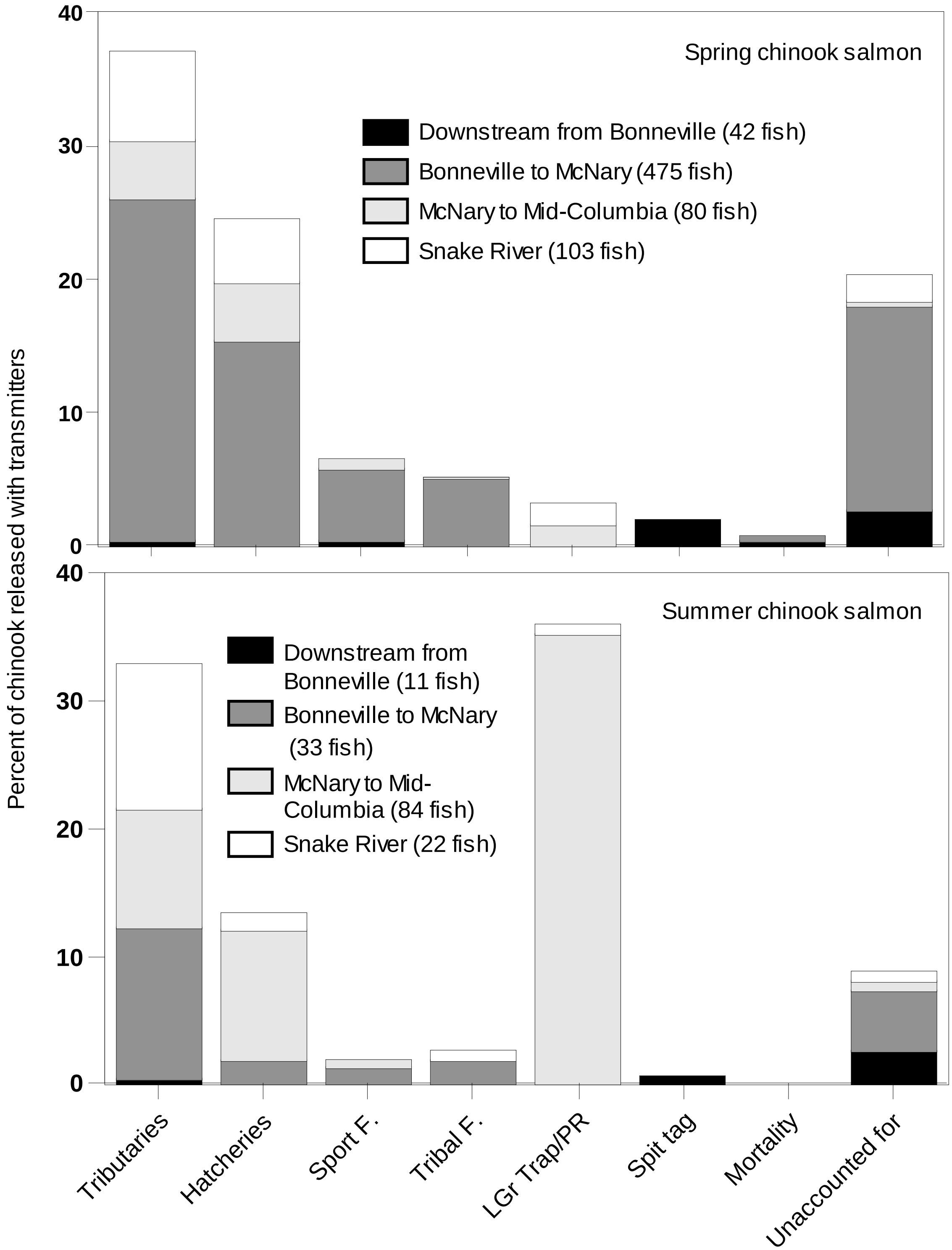

Figure 52. Our best estimate of the percentage of spring and summer chinook salmon with transmitters in 1996 that ended up in tributaries, at hatcheries, in fisheries, passing Priest Rapids Dam, transported to hatcheries from Lower Granite trap, found after they regurgitated their transmitters, or were unaccounted for.

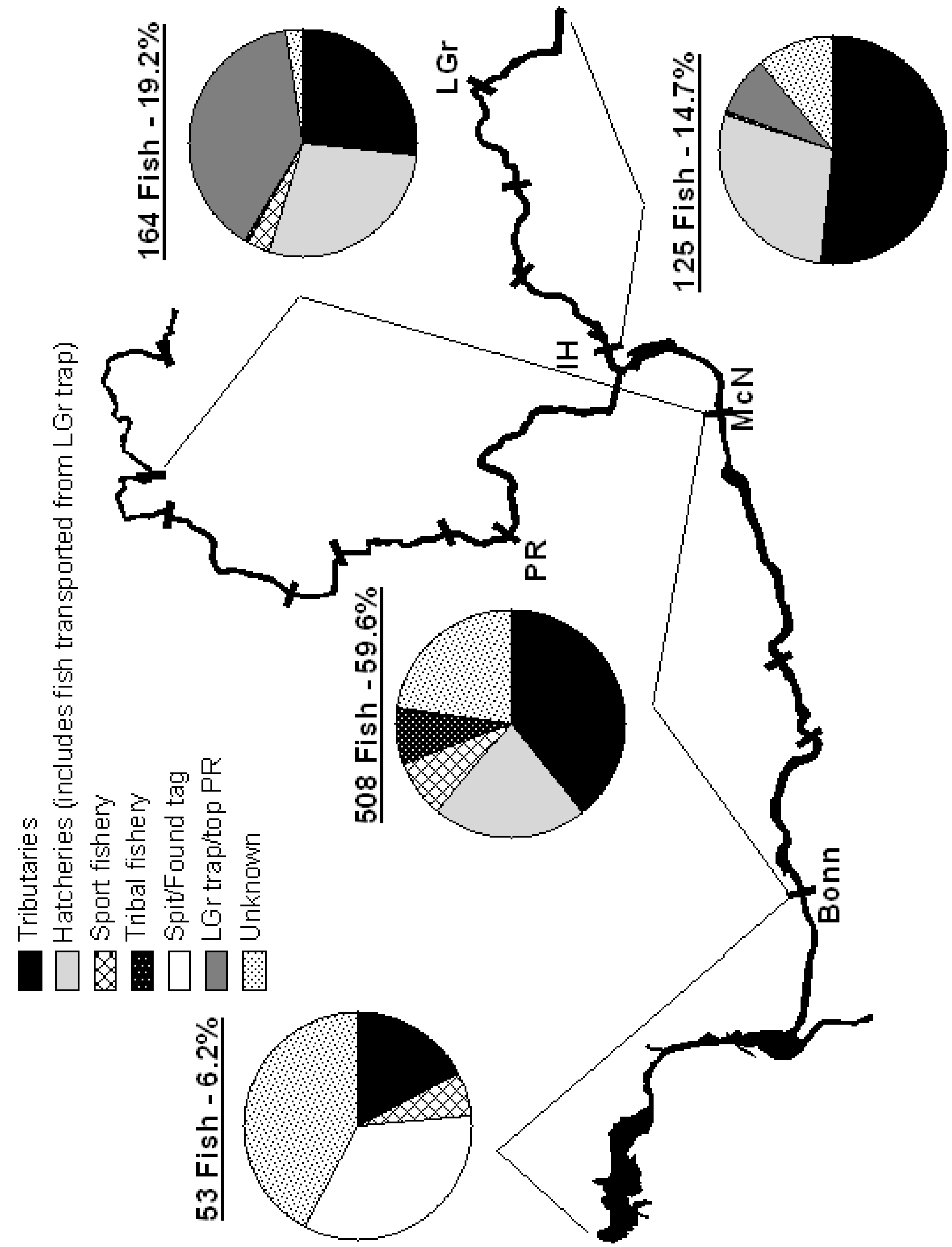

Figure 53. Our best estimate of the fate of 853 spring and summer chinook salmon with transmitters in 1996, by basin subsection. Pie graphs show percentage of fish in tributaries, hatcheries, fisheries, at the top of Priest Rapids Dam, in the Lower Granite trap, with found/regurgitated transmitters, and those unaccounted for.

Table 37. Our best estimate of the fate of 853 chinook salmon released in 1996 downstream from Bonneville Dam with transmitters that had fin-clips or were unclipped when tagged, with the numbers released, numbers and percents of total that ended up in the various sections of the Columbia River basin.

	All salmon		Fin-clipped salmon		Unclipped salmon	
	Number	Percent	Number	Percent	Number	Percent
Number released	853	100	217	100	636	100
Downstream from Bonneville Dam	**53**	**6.2**	**13**	**6.0**	**40**	**6.3**
Entered a tributary	9	1.1	1	0.5	8	1.3
Sport fishery	3	0.4			3	0.5
Regurgitated transmitter	15	1.8	3	1.4	12	1.9
Found in non-spawning area	3	0.4	1	0.5	2	0.3
Unaccounted for	23	2.7	8	3.7	15	2.4
Bonneville to McNary dams	**508**	**59.6**	**121**	**55.8**	**387**	**60.8**
Entered a tributary	199	23.3	39	18.0	160	25.2
Recaptured at hatchery	112	13.1	25	11.5	87	13.7
Sport fishery	41	4.8	9	4.1	32	5.0
Tribal fishery	39	4.6	10	4.6	29	4.6
Found in non-spawning area	2	0.2			2	0.3
Unaccounted for	115	13.5	38	17.5	77	12.1
Mid-Columbia River	**164**	**19.2**	**24**	**11.1**	**140**	**22.0**
Entered a tributary	44	5.2	4	1.8	40	6.3
Recaptured at hatchery	46	5.4	7	3.2	39	6.1
Sport fishery	5	0.6	1	0.5	4	0.6
Tribal fishery	1	0.1			1	0.2
Top of Priest Rapids Dam	64	7.5	10	4.6	54	8.5
Unaccounted for	4	0.5	2	0.9	2	0.3
Snake River basin	**125**	**14.7**	**57**	**26.3**	**68**	**10.7**
Entered a tributary	64	7.5	19	8.8	45	7.1
Recaptured at hatchery[a]	35	4.1	29	13.4	6	0.9
Tribal fishery	1	0.1	1	0.5		
At L. Granite Trap, no transmitter	12	1.2	6	2.8	6	0.9
Unaccounted for	14	1.6	3	1.4	11	1.7
Other[b]	**3**	**0.4**	**2**	**0.9**	**1**	**0.2**
			Basin-wide summary			
Recorded in tributaries	**316**	**37.0**	**63**	**29.0**	**253**	**39.8**
Recaptured at hatcheries	**193**	**22.6**	**60**	**27.6**	**132**	**20.8**
Reported harvest	**90**	**10.6**	**21**	**9.7**	**69**	**10.8**
Last record at Lower Granite Dam[c]	**11**	**1.3**	**5**	**2.3**	**6**	**0.9**
Last record at Priest Rapids Dam	**64**	**7.5**	**10**	**4.6**	**54**	**8.5**
Regurgitated transmitters	**20**	**2.3**	**4**	**1.8**	**16**	**2.5**
Other[b]	**3**	**0.4**	**2**	**0.9**	**1**	**0.2**
Transmitters unaccounted for	**156**	**18.3**[c]	**51**	**23.5**	**105**	**16.5**

[a] includes 12 spring chinook recaptured at Lower Granite Trap, transported to Lookingglass Hatchery.

[b] 1 fish recaptured at Rogue River hatchery; 1 transmitter removed from fish at Bonneville adult trapping facility; 1 fish recaptured at unknown location.

[c] lost transmitters before trapped at Lower Granite Dam, not recorded upstream from trap.

[d] includes 7 fish that passed Lower Granite Dam with transmitter, that were not recorded at upstream.

Columbia River section were spring chinook salmon, many of which returned to the Yakima River. Overall, 38% of spring chinook in the mid-Columbia returned to tributaries, 39% returned to hatcheries, 14% were last recorded at the top of Priest Rapids Dam, and 5.0% were harvested in sport fisheries (Figure 54). Fifty-one percent of the fish that returned to the mid-Columbia River section were summer chinook salmon, almost all of which passed Priest Rapids Dam. Overall, 63% of the summer chinook were last recorded at the top of Priest Rapids Dam, 17% entered tributaries, 18% were recaptured at hatcheries, and less than 2% were unaccounted for or reported as recaptures in sport fisheries (Figure 55).

Of the 125 salmon that ended up in the Snake River Basin, 64 (52%) returned to tributaries, 35 (28%) were recaptured at hatcheries, 11 (9%) were recaptured at the Lower Granite trap and released without transmitters, and 14 (11%) were unaccounted for, including 7 last recorded at the top or Lower Granite Dam (Table 36, Figure 53). Eighty-two percent of the fish that ended up in the Snake River basin were spring chinook salmon and 18% were summer chinook. About 46% were fin-clipped and 54% did not have clips (Table 37). Spring chinook primarily returned to tributaries (46%) and hatcheries (31%) (Figure 52), while the relatively small number of summer chinook in the Snake River basin mostly returned to tributaries (77%) (Figure 55).

The proportion of radio-tagged chinook salmon that were unaccounted for (156 of 853 fish outifitted with transmitters = 18.3%) were primarily fish last recorded at dams and in lower Columbia River reservoirs. Fish that were unaccounted for may have been harvested but not reported to us, may have regurgitated tags that were not recovered, may have entered tributaries undetected, may have spawned at main stem locations, or may have been mortalities with unrecoverable transmitters. Fish that regurgitated tags at the release site were not considered unaccounted for. Of the 156 fish we designated unaccounted for, 149 (17.5% of 853) were last recorded at dams or in reservoirs downstream from Lower Granite or Priest Rapids dams, and 7 (0.8% of 853) were last recorded at the top of Lower Granite Dam and not recorded at receivers upstream or located by mobile trackers.

Ninety-two percent of the 156 unaccounted for fish were spring chinook salmon, and 67% did not have fin clips. The largest proportion of unaccounted for fish (42.9%) were last recorded between the top of Bonneville Dam and the tailrace of The Dalles Dam, with 30 fish in the Bonneville Dam pool, 22 fish at The Dalles Dam, and 15 fish at the top of Bonneville Dam (Table 38). Another 30 (19.2%) were last recorded between the top of The Dalles Dam and the John Day Dam tailrace, 23 (14.7%) were last recorded downstream from Bonneville Dam, and 18 (11.5%) were last recorded between the top of John Day Dam and the McNary Dam tailrace. Relatively small proportions of the unaccounted for fish were last recorded upstream from McNary Dam: 8 (5.1%) were between the top of McNary and either the Ice Harbor or Priest Rapids tailraces, and 3 (1.9%) were last recorded between the top of Ice Harbor Dam and the tailrace of Lower Granite Dam (Table 38). The 7 fish last recorded at the top of Lower Granite Dam made up 6.1% of the unaccounted for fish.

Table 38. Last known locations for 156 chinook salmon unaccounted for by records in tributaries, at hatcheries, in fisheries, or recovery of transmitters in any other way throughout the monitored reach of the main stem Columbia and Snake rivers in 1996. Unaccounted for fish in each section and as a percentage of all fish in section, and percent of all unaccounted for fish and all fish released that retained transmitters.

River section Last record location	Fish unaccounted for	All fish in section	Percent unaccounted for	Percent of 156 fish	Percent of 838 fish
Downstream from Bonneville	**23**	**53**	**43.4**	**14.7**	**2.7**
Downstream from dam	15		28.3	9.6	1.8
At Bonneville Dam	8		15.1	5.1	1.0
Top of Bonneville to The Dalles	**67**	**335**	**20.0**	**42.9**	**8.0**
Top of Bonneville Dam	15		4.5	9.6	1.8
Bonneville pool	30		8.9	19.2	3.6
At The Dalles Dam	22		6.6	14.1	2.6
Top of The Dalles to John Day	**30**	**101**	**29.7**	**19.2**	**3.6**
Top of The Dalles Dam	5		5.0	3.2	0.6
The Dalles pool	8		7.9	5.1	1.0
At John Day Dam	17		16.8	10.9	2.0
Top of John Day to McNary	**18**	**72**	**25.0**	**11.5**	**2.1**
Top of John Day Dam	14		19.4	9.0	1.7
John Day pool	1		1.4	0.6	0.1
At McNary Dam	3		4.2	1.9	0.4
Top of McNary to Ice Harbor or Priest Rapids dams	**8**	**56**	**14.3**	**5.1**	**1.0**
Top of McNary Dam	1		1.8	0.7	0.1
Snake River mouth	3		5.4	2.0	0.4
At Ice Harbor Dam	1		1.8	0.7	0.1
At Priest Rapids Dam	3		5.4	2.0	0.4
Top of Ice Harbor to L. Granite	**3**	**7**	**42.9**	**1.9**	**0.4**
Top of Ice Harbor Dam	2		28.6	1.3	0.2
Lower Monumental pool	1		14.3	0.7	0.1
Upstream from Priest Rapids: data not available					
Upstream from Lower Granite	**7**	**114**	**6.1**	**4.5**	**0.8**
Other[a]	**0**	**3**	**0**	**0**	**0**
Total	**159**		**100**	**100**	**18.6**[b]

[a] 1 fish recaptured at Rogue River hatchery; 1 transmitter removed from fish at Bonneville adult trapping facility; 1 fish recaptured at unknown location

[b] 156 of 853 fish (18.3%) outfitted with transmitters were unaccounted for

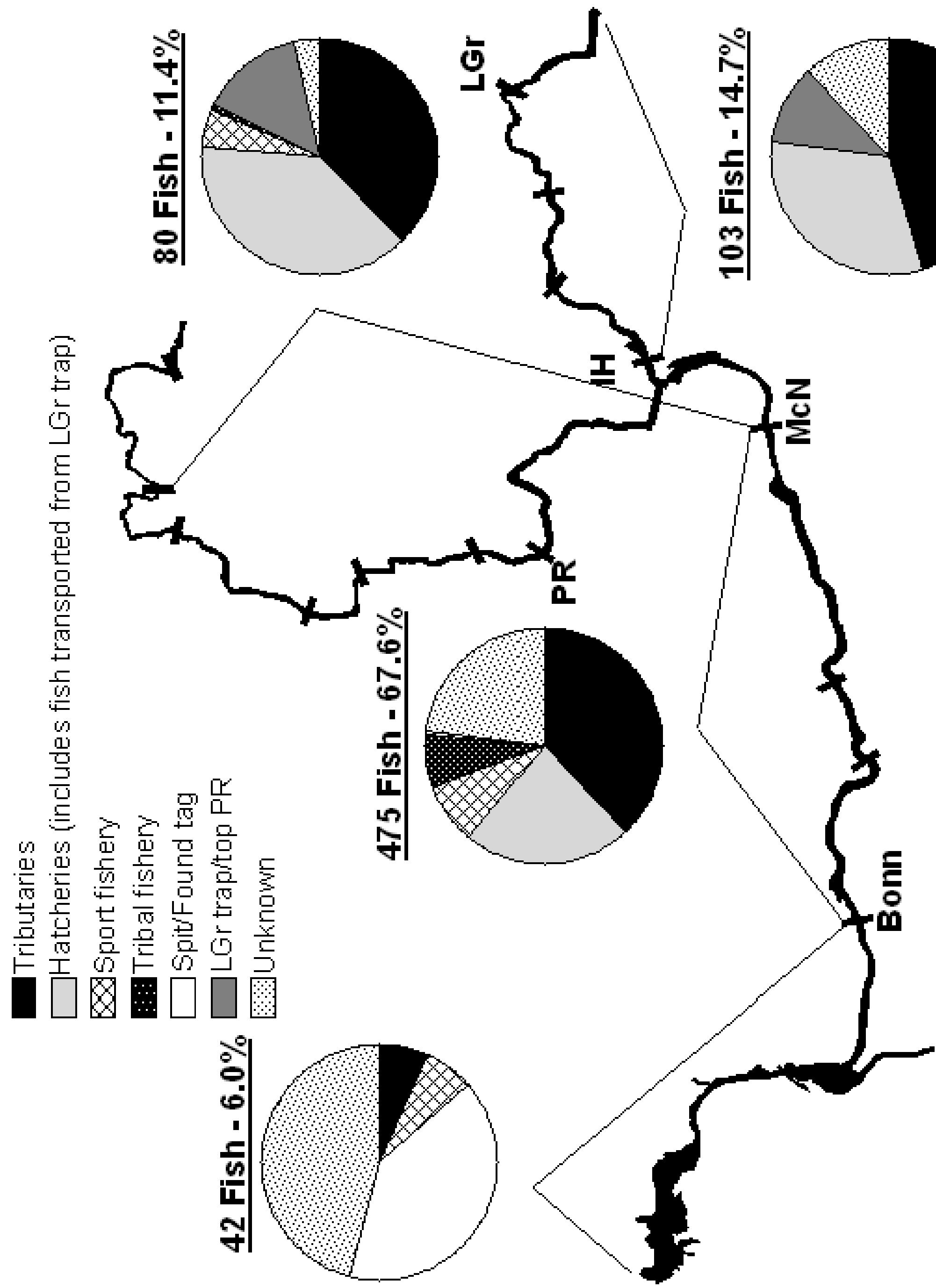

Figure 54. Our best estimate of the fate of 703 spring chinook salmon with transmitters in 1996, by basin subsection. Pie graphs show percentage of fish in tributaries, hatcheries, fisheries, at the top of Priest Rapids Dam, in the Lower Granite trap, with found/regurgitated transmitters, and those unaccounted for.

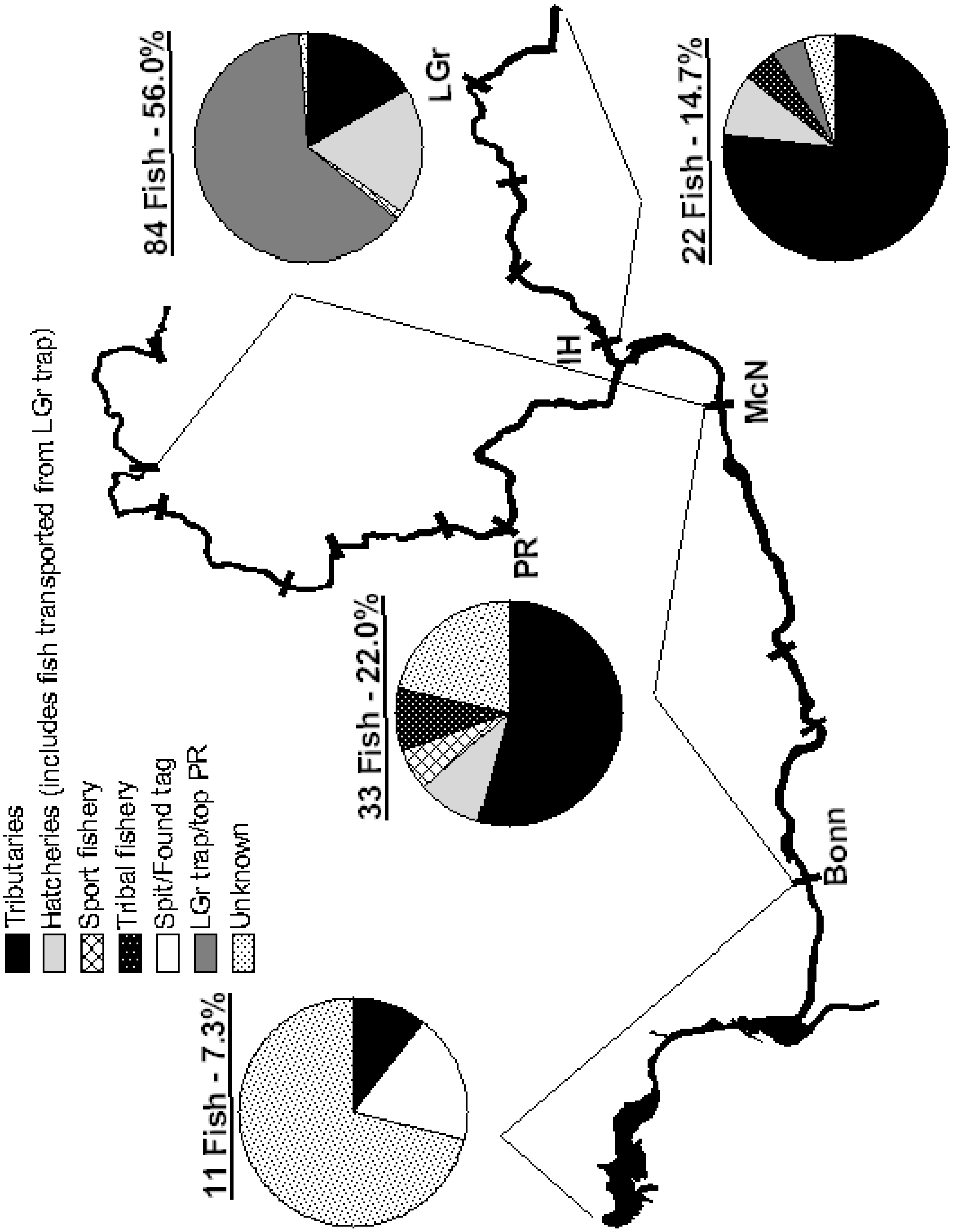

Figure 55. Our best estimate of the fate of 150 summer chinook salmon with transmitters in 1996, by basin subsection. Pie graphs show percentage of fish in tributaries, hatcheries, fisheries, at the top of Priest Rapids Dam, in the Lower Granite trap, with found/regurgitated transmitters, and those unaccounted for.

We also calculated the proportion unaccounted for in each section of the system. Downstream from Bonneville Dam, where we estimate 53 fish ended up, 23 (43.4%) were unaccounted for (Table 38). Between Bonneville and The Dalles dams 67 of 335 chinook salmon (20.0%) were unaccounted for, and 30 of 101 (29.7%) were unaccounted for between The Dalles and John Day dams. Eighteen of 72 (25%) were unaccounted for between John Day and McNary dams, and 8 of 56 (14.3%) were unaccounted for from McNary to Priest Rapids and Ice Harbor dams. Three of 7 (42.9%) last recorded between the top of Ice Harbor Dam and the tailrace of Lower Granite Dam were unaccounted for, as were 7 of 114 (6.1%) that passed over Lower Granite Dam or were transported from the Lower Granite trap to a hatchery (Table 36).

Discussion

In 1996 we were able to successfully use radio telemetry on a large scale to assess and evaluate the passage of adult salmon and steelhead as they migrated past dams and through reservoirs in the Columbia and Snake rivers on their way to spawning grounds and hatcheries. We examined passage rates, fallback behavior, fishway use, recaptures in fisheries and at hatcheries, survival to tributaries, and final fate from release downstream from Bonneville Dam into tributaries and upstream to Priest Rapids and Lower Granite dams.

Compared to the previous 10-year average, the 1996 spring and summer chinook salmon run was about two-thirds of average at Bonneville Dam, and less than 54% of the average at upriver dams. An unusually small proportion of the spring chinook salmon counted at Bonneville Dam migrated into the Snake River (12%) and mid Columbia River upstream from Priest Rapids Dam (5%). Spring chinook salmon counts were 24% of average at Lower Granite Dam and 18% of average at Priest Rapids Dam. Most spring chinook salmon entered lower Columbia River tributaries. About 68% of the summer run of chinook salmon passed Priest Rapids Dam, and the total count there was about 75% of average. Peak spring chinook salmon counts at all dams were two to three weeks later than average, perhaps because flow and spill in 1996 were nearly double the prior 10-year average, turbidity was higher than average, and water temperatures were consistently one to two degrees colder than average. Spill was nearly continuous at all dams during most of the 1996 spring and summer chinook salmon migration. Spill at Bonneville and McNary dams was about 45% of total flow, spill at The Dalles Dam was about 63% of total flow, and at John Day Dam spill was about 20% of total flow during the migration period.

One of the important questions addressed in the study was whether salmon and steelhead collected in the Bonneville adult trapping facility adjacent to the Washington- shore ladder were representative of the overall run. We mobile-tracked 104 chinook salmon (12% of those released with transmitters in 1996) through the 9.5 km stretch of Columbia River between the release sites and Bonneville Dam. The tracked fish tended to move along both shorelines, but 66% crossed the river channel at least once while returning to the dam. Salmon taken from the Washington-shore ladder at Bonneville Dam did not return there at a higher rate than to the other fishways; about half the returning fish passed through the Bradford Island and half the Washington-shore fishways at the dam. Tailrace and fishway behavior and passage times for the 104 fish we tracked were similar to that of all radio-tagged fish in 1996. Radio-tagged fish that returned to tributaries along the north shore of the Bonneville Dam pool passed the two fishways at Bonneville Dam in approximately equal proportions. The proportion of radio-tagged salmon recorded at each succeeding upstream dam was similar to the proportion of salmon counted at Bonneville Dam that passed the upstream dams, which was additional evidence that fish selected for tagging were probably representative of the run in 1996.

Of the 853 spring and summer chinook salmon we released with transmitters in 1996, we could account for 697 (81.7%) of the fish or their transmitters in that we knew their final fates. Of 853, 37% of the fish ended up in tributaries, 22.6% at hatcheries or fish weirs in tributaries, 10.6% were reported as harvested in sport or tribal fisheries, 7.5% had last records at the top of Priest Rapids Dam, 1.4% had lost their transmitters when recaptured at Lower Granite Dam, and 2.3% had regurgitated their transmitters near the release site or their transmitters were found in non-spawning areas. The remaining 18.3% were classified as being unaccounted for because they were last recorded at dams or in reservoirs and we do not know if they died before spawning, were harvested but not reported to us, or entered tributaries undetected (perhaps because they regurgitated their transmitters).

Transmitter retention was quite good overall: 15 salmon (1.8%) regurgitated transmitters near the release sites, 5 (0.6%) transmitters were found in non-spawning areas and may have been regurgitated (or fish died), 10 of 203 (4.9%) salmon recaptured at hatcheries had lost their transmitters, and 13 of 114 fish (11.4%) that were recorded passing Lower Granite Dam or were recaptured at the Lower Granite trap had lost their transmitters. Regurgitation rates for fish recaptured at hatcheries or fish weirs was lower than for fish recaptured at Lower Granite Dam partly because many of the recaptured fish entered lower Columbia River hatcheries and did not have as far to migrate as fish recaptured at Lower Granite Dam. Overall, the known regurgitation rate was 5.0% (43 of 853). Some of the 156 transmitters we could not account for may have been regurgitated in reservoirs where we were unable to locate them.

Of the 838 salmon released that did not regurgitate their transmitters at the release sites, 99% were recorded back at Bonneville Dam and 96.5% were known to have passed the dam. Fifty-nine percent proceeded upriver and passed The Dalles Dam, 45% John Day Dam, 35% McNary Dam, 15% Ice Harbor Dam, 14% Lower Granite Dam, and 14% Priest Rapids Dam. A small proportion of the tagged salmon passed each dam without being recorded at tailrace or top-of-ladder receivers, but were usually recorded in the fishways at the dam and at upstream receiver sites; receiver efficiency averaged 91% for tailrace sites, 93% for top-of-ladder sites, and 96% for tributary sites.

Median times for salmon to pass individual dams in 1996 were less than 1.6 d, and were less than one day at Bonneville, The Dalles, and Ice Harbor dams. At each dam, however, 15% to

20% of the radio-tagged fish took more than 5 d to pass, and all time- to-pass distributions were right-skewed, with mean times higher than medians. Times to pass dams and distributions in 1996 were consistent with chinook salmon passage times observed in radio-telemetry assessments at the Snake River dams in 1991 to 1993 (Bjornn et al. 1998). In 1996, we found that fallout from transition pools into tailrace areas contributed to passage delays at individual dams.

Higher than average flows and nearly continuous spill during the spring and summer chinook salmon migration period in 1996 did not appear to have significant adverse effects on the passage of most chinook salmon. Peak chinook salmon counts at Bonneville Dam occurred during a temporary decrease in flow, but counts peaked with flow and spill at Ice Harbor and McNary dams. In general, passage times tended to be longer under higher flow and spill conditions, but correlations of passage time and flow and spill were weak despite a large range of in-river conditions. An episode of high turbidity in early May appeared to cause a temporary decrease in chinook salmon passage at Bonneville Dam and similar high-turbidity periods in late May in the Snake River coincided with decreased counts of salmon when we would not have expected nadirs. As with flow and spill, however, turbidity was not strongly correlated with time to pass the dams.

Because all environmental conditions varied continuously, it was difficult to separate the effects of high flow, spill, and turbidity on passage times of salmon. Stepwise multiple regression models of passage times at individual dams tended to select passage date (a surrogate for water temperature) as the best predictor of passage times at lower Columbia River dams. As the migration season progressed from spring to summer, passage times decreased. Mean and median summer chinook salmon passage times were significantly lower than those for spring chinook salmon at most dams.

Spring and summer chinook salmon migrated through reservoirs relatively quickly in 1996. Median rates were 43, 45, 62, and 56 km/d through the four lower Columbia River reservoirs. Rates were from 40 km/d to 61 km/d for spring chinook salmon and from 55 km/d to 64 km/d for summer chinook salmon. Summer chinook salmon migration rates were significantly faster ($P < 0.005$) through the Bonneville and The Dalles pools, perhaps in part because most summer fish were bound for upstream sites and made few stops at lower Columbia River tributaries.

Median passage times from the Bonneville Dam tailrace over several dams and through reservoirs were 11.9 d to the top of McNary Dam, 16.8 d to the top of Ice Harbor Dam, 27.2 d to the top of Lower Granite Dam, and 16.7 d to the top of Priest Rapids Dam. Median times for summer chinook salmon were 4 d to 9 d shorter than for spring chinook salmon, and differences were significant ($P < 0.005$) for fish that passed McNary, Lower Granite, and Priest Rapids dams, as well as Ice Harbor Dam ($P < 0.05$). Of the total migration time from Bonneville Dam tailrace to Lower Granite Dam, approximately 45% of the median time was spent passing dams (not including Lower Monumental and Little Goose dams) and 55% was spent passing through reservoirs. For the total migration time from Bonneville to past McNary and Ice Harbor dams, about 60% of the median time was spent passing dams. These results are consistent with previous studies where adult chinook salmon made up for delays at dams by moving rapidly through reservoirs (Bjornn et al., 1992, 1998), and spring chinook salmon migrated slower than summer chinook salmon (Gibson et al. 1979).

In multiple regression models, the best predictors of upstream passage times past multiple dams and reservoirs were the date fish passed the Bonneville Dam tailrace (spring chinook salmon migrated more slowly than summer fish) and the number of times fish fell back at main stem dams during their migration, because fallback events delayed passage significantly. Turbidity, spill, and flow conditions during the migration were secondary as predictors of total passage times, although they did improve model fit in some cases. Passage date was less significant in models of passage from Ice Harbor Dam to the top of Lower Granite Dam. Turbidity and spill at the time fish passed Lower Granite Dam were the best predictors of total passage time through the lower Snake River.

A significant number of chinook salmon with transmitters fell back over one or more of the four lower Columbia River dams in 1996. Twenty-three percent (185 fish) of the chinook salmon that passed Bonneville Dam fell back at one or more dams 326 times in 1996. Forty-one percent of all fallback events occurred at Bonneville Dam. Twelve to 15% of the fish that passed Bonneville, The Dalles and John Day dams fell back, about 9% of those that passed McNary and Ice Harbor dams fell back, 5% fell back after passing Priest Rapids Dam, and 1% fell back after passing Lower Granite Dam. A number of factors seemed to be important in the percentage of fish that fall back over dams, including: location of fishway exits (Bonneville Dam with Bradford Island fishway, Lower Granite and Little Goose dams with exits on shoreline away from spillways), location of dam in relation to tributaries used for spawning (The Dalles and John Day dams), location of dams in relation to a large-river confluence (Ice Harbor Dam), amount of water spilled at dam, and behavior of the fish. The Bradford Island ladder, which exits into the forebay on Bradford Island at Bonneville Dam, had the highest fallback rates for all ladders and dams. Many salmon exited the Bradford Island fishway and followed the shoreline around the island into the spillway forebay at the dam, where a relatively high proportion fell back. Previous studies of fallback behavior at the Bradford Island fishway and lower Columbia dams were reported by Bjornn et al. (1999b), Young et al. (1975; 1978), Liscom et al. (1977; 1979), Monan and Liscom (1975), Ross (1983), and Shew et al. (1985), among others.

Fallback rates increased with flow and spill at all lower Columbia River dams, and particularly with spill at Bonneville Dam, but correlations were not robust. With the telemetry records we have at the dams, and because few fallbacks occurred when there was no spill, we believe most fish fell back over the dams via the spillways. Full analyses of fallback behavior and circumstances contributing to fallback at Bonneville, The Dalles, and John Day dams were reported in Bjornn et al. (2000b; 2000c; 2000d).

About 66% of chinook salmon with transmitters that fell back at the Columbia and Snake river dams eventually reascended the fishways and passed upstream. Reascension rates varied by dam with 89% of the fish that fell back at Bonneville Dam reascending, 62% at The Dalles Dam, 64% at John Day Dam, 37% at McNary Dam, 70% at Ice Harbor Dam, and 100% at Priest Rapids and Lower Granite dams. The lower reascension rates at The Dalles, John Day, and McNary dams were because more fish that passed those dams entered tributaries downstream from the dams than at Bonneville Dam or the upper dams. Overall, about 58% of the fish that fell back and did not reascend entered tributaries downstream from the fallback location. We could not identify if such behavior was due to straying or temporary errors in homing.

Fish that fallback and reascend add a positive bias to estimates of escapement based on fish counts at dams because fallback fish that did not reascend did not end up upstream from the dam, and fish that reascended were counted more than one time. Adjustment factors for fallback and reascension ranged from approximately 0.85 at The Dalles Dam and 0.86 at Bonneville Dam to 0.99 at Lower Granite Dam, values that we believe were fairly precise for 1996, but should not be extrapolated to other years. Additional years of data are needed to form a reliable relation between fallbacks, passage through navigation locks, fish counts and environmental variables. Using our adjustment factors for chinook salmon with transmitters, we estimated that the counts of spring and summer chinook salmon provided by the USACE (1996) had positive biases ranging from about 75 to 700 fish at Lower Granite, Ice Harbor, and Priest Rapids dams, and from 2,600 to 9,250 fish at lower Columbia River dams.

Fallback at all dams appeared to have negative consequences for chinook salmon. Falling back at the dams added significantly ($P < 0.05$) to overall passage times, increasing median times from release past multiple projects by 4 to 7 d. Mean and median time from release to the last passage of a dam were significantly longer ($P < 0.001$) for fish that fell back one or more times and then passed Bonneville, The Dalles, John Day, McNary, and Ice Harbor dams and longer ($P < 0.05$) for fish that passed Lower Granite or Priest Rapids dams than fish that did not fallback. A single fallback event caused significant ($P < 0.05$) delays for salmon from release to passage at all dams except Lower Granite and Priest Rapids. Spring chinook salmon that fell back had the longest upriver passage delays due to fallback. Summer chinook salmon experienced shorter delays due to fallback, but times to pass the upriver dams were still significantly different from fish that did not fallback. It is important to note that delays associated with fallback were only evident for those fish that survived to reascend dams. Chinook salmon bound for upriver sites that experienced direct or delayed mortality because of a fallback could not be included in passage time comparisons. Some of the fish that fell back over dams and did not reascend could not be accounted for and may have died as a result of falling back at a dam. However, we believe that direct mortalities from fallbacks must be relatively infrequent given that some fish fell back several times and still succeeded in migrating to upriver tributaries. In some cases a fish may have fallen back over a dam because it was sick or injured.

Fish that fell back at any location survived to major tributaries or the top of

Priest Rapids Dam at lower rates than fish that did not fall back. Survival for fish that fell back at any dam was 74.1%, compared to 77.7% for fish that did not fall back at any location, a difference that was not significant ($P > 0.10$). Chinook salmon that fell back at Bonneville Dam survived at a significantly ($P < 0.10$) lower rate (72.3%) than fish that did not fall back at Bonneville Dam (79.3%). Based on survival rates of radio-tagged salmon in 1996, we estimated that about 400 untagged chinook salmon probably did not survive to enter tributaries because of fallback events during their migration. We were unable to determine whether fallback fish would have been less likely to survive regardless of fallbacks than those that did not fallback.

Chinook salmon that fell back at Bonneville Dam were eventually recorded at tributary and main stem sites throughout the Columbia and Snake River basins, roughly in proportion to overall distributions. About 21% of the Bonneville Dam fallback fish were last recorded at Snake River sites, 8% were recorded at mid-Columbia sites upriver from McNary Dam, and the majority entered tributaries to the lower Columbia River or were last recorded in the lower Columbia River. Salmon that fell back at other dams also did not appear to be from any portion of the run or from particular tributaries.

In general, chinook salmon entered lower Columbia River tributaries early in the migration season and progressively later at mid-Columbia and Snake River tributaries. Median arrival dates at lower Columbia River tributaries were mainly in mid-May, while median arrivals at Lower Granite Dam, the Snake River near Asotin and the Clearwater River were in early to mid-June. In this report, we have used the date of 1 June for the separation of spring from summer chinook salmon counted at Bonneville Dam. The reader should keep in mind that the tails of the time-of-migration distributions for the two groups overlap, and thus, some spring chinook salmon migrate after the 1 June cutoff date and some summer chinook migrate before. Furthermore, the proportions of each group migrating past Bonneville Dam before or after the cutoff date probably varies from year to year.

Spring chinook salmon made up the majority of returns to lower Columbia River tributaries and made up the most of the Snake River run. The larger summer chinook salmon primarily returned to Priest Rapids Dam, especially the last half of the run, with some summer fish returning to the Salmon and Imnaha rivers, mostly from the first half of the run. We were able to identify the range of dates when salmon with transmitters from specific stocks passed Bonneville Dam, but passage distributions for most stocks overlapped. It was not possible, for example, to differentiate spring chinook salmon that eventually entered the Snake River from those that returned to Bonneville pool tributaries. Chinook salmon with transmitters that entered the Snake and Deschutes rivers passed Bonneville Dam throughout the April-July migration season, while lower Columbia River stocks passed primarily in April and May, and mid-Columbia stocks contained a few fish that passed during the spring period, but most were in the segment that passed in June and especially July. During their migrations, some chinook salmon entered tributaries other than their final destination tributary, but stopovers were generally short, particularly when compared to those of steelhead.

An important goal of the study was to give an overall accounting of the final fate of radio-tagged chinook salmon that might be applied to the run as a whole. About 76% of the 838 chinook salmon that retained transmitters at time of release in 1996 survived to enter tributaries, passed over Priest Rapids Dam, or returned to the Lower Granite adult trap. Summer chinook salmon with transmitters survived at a significantly ($P < 0.01$) higher rate (90%) than spring chinook salmon (73%). Even though a high proportion of the summer chinook returned to the top of Priest Rapids Dam and migrated a shorter distance than spring and summer chinook salmon that entered the Snake River, the higher survival of summer chinook salmon is probably real. A significantly ($P < 0.10$) higher percentage (78%) of chinook salmon without fin clips survived to tributaries or the top of Priest Rapids Dam than fish with fin clips (70%).

In 1996 our monitoring of radio-tagged salmon in the mid Columbia and Snake river basins was not as extensive as in previous Snake River studies because of funds and equipment limits. For 1996, we classified fish as having survived to tributaries if they were recorded in tributaries (including recaptures at hatcheries and traps), at the top of Priest Rapids Dam, recaptured at Lower Granite Dam and transported to hatcheries, and recorded on receivers at the mouth of the Clearwater River and as they passed up the Snake River near Asotin WA. Because some fish undoubtedly died before spawning upstream from Priest Rapids Dam and the uppermost receiver sites in the Snake River, the survival rates should not be viewed as survival to spawning.

About 40% of all chinook salmon outfitted with transmitters in 1996 were reported recaptured in fisheries, at hatcheries, weirs or traps (not including the Bonneville or Lower Granite traps), at spawning grounds, or their transmitters were found along river corridors. Fifteen percent of recaptures were in sport fisheries, 13% in tribal fisheries, 61% at hatcheries, weirs or traps and 11% at spawning grounds or through found transmitters. One-third of all recaptures were at hatcheries in the Wind, Little White Salmon and Deschutes rivers, and another 13% were in those tributaries at locations other than hatcheries. About 30% of summer chinook salmon and 41% of spring chinook salmon were reported recaptured. Twelve percent of all tagged salmon were recaptured in the Snake River drainage, 18% in the mid-Columbia or its tributaries upriver from the McNary pool, and 13% in the main stem Columbia River downstream from McNary Dam.

Our best final-distribution estimate for all fish with transmitters was 6.2% downstream from Bonneville Dam, 59.6% between Bonneville Dam and the McNary Dam tailrace, 19.2% in the mid-Columbia upstream from McNary Dam, and 14.7% in the Snake River basin. Maximum escapement to tributaries for spawning escapement was 68.5%, with 37% to tributaries, 22.6% to hatcheries, and 8.9% that passed Priest Rapids Dam, were transported from the Lower Granite trap, or were recaptured at the trap without transmitters. About 10.6% were reported to us as being recaptured in sport or tribal fisheries, 2.3% of transmitters were found in non-spawning areas, and 18.3% were unaccounted for. Fish that were unaccounted for may have been harvested but not reported to us, may have regurgitated transmitters that were not recovered or the fish was recaptured and not identified with the secondary tag, may have entered tributaries undetected, may have spawned at main stem locations, or may have died and the transmitters were not located. More than 95% of the unaccounted for fish were last recorded at dams or in reservoirs downstream from Lower Granite Dam, and 92% were spring chinook salmon. The largest number of unaccounted-for fish were last recorded at Bonneville or The Dalles dams or their reservoirs. See Stuehrenberg et al. (1978), Liscom et al. (1978), Turner et al. (1984), and Gibson et al. (1979) for additional comments on chinook salmon unaccounted for between dams.

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